U. S. DEPARTMENT OF AGRICULTURE,

BUREAU OF ENTOMOLOGY—BULLETIN No. 79.

L. O. HOWARD, Entomologist and Chief of Bureau.

FUMIGATION INVESTIGATIONS IN CALIFORNIA.

By R. S. WOGLUM,

Special Field Agent.

[CHEMICAL WORK PERFORMED BY THE MISCELLANEOUS DIVISION OF THE BUREAU OF CHEMISTRY.]

ISSUED JUNE 11, 1909.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1909.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Entomology,
Washington, D. C., February 6, 1909.

Sir: I have the honor to transmit herewith a manuscript entitled "Fumigation Investigations in California." It is a preliminary report on the subject, and contains much information which will be of direct practical value to citrus growers. The report is one of progress, and much of the information has already been made available to the public by means of lectures and field demonstrations, but it is important that it should be put in published form so as to give it wider currency. The subject is one that requires abundant illustration, and the figures and plates submitted are all deemed necessary for the full understanding of the text.

Respectfully,

L. O. Howard,
Entomologist and Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

Fumigation under tents with hydrocyanic-acid gas has been the principal means of controlling scale-insects on citrus fruit trees in California for many years. Most of the commercial orchards in the State are fumigated at intervals of one or two years, at a cost ranging from 25 cents to $1.50 a tree, or a probable total annual expenditure of about $1,500,000, on the basis of fumigation of 50 per cent of the trees each year. It becomes, therefore, a matter of very great importance to conduct the operation of fumigation in the most effective and economical manner. The work being done on the subject in California by this Bureau is aimed to thoroughly standardize the process. It was undertaken in response to urgent demands from the horticultural commissioners of the principal citrus-fruit-producing counties of California, and of many prominent growers. The need of this investigation was most urgently championed by Mr. J. W. Jeffrey, former secretary of the Los Angeles County horticultural commission and now State commissioner of horticulture of California. Recognizing the general usefulness of the process of fumigation, Mr. Jeffrey called attention strongly to the unevenness of results in the work of different manipulators and against different scale pests, and that the whole practice had grown up experimentally without ever having been given thorough scientific examination. He urged that such an examination necessitated carefully conducted and recorded field work, supplemented by chemical tests of ingredients and the determination of reactions, and expert study of the physiological effect of the gas on the trees and fruit; in other words, to remove the process from the mere guesswork of the field man and to place it on an exact scientific basis.

This investigation has been under the direct charge of the writer, who made a personal study of the situation in southern California in September and October, 1907, and planned the work to cover the following subjects:

(1) Dosage, or the amount of gas and duration of exposure necessary for different purposes. The strength of gas necessary to effectively control the three prominent scale pests of citrus trees in California, namely, the red scale, the purple scale, and the black scale, under different climatic conditions, as in the drier foothills regions and

the moister coastal strip; for different seasons of the year; and for the different growing conditions of the tree, as whether in fresh leafage, or in bloom, or with different stages of the developing fruit.

(2) Physiological effect on the tree and fruit. There is some evidence to show that the gas may have a stimulating effect on the tree.

(3) Mechanical equipment. An important economical consideration in gassing is the employment of the most suitable tent cloths, and their treatment to give durability and imperviousness; also, the best mechanical means of hoisting tents over the trees. To be determined under this heading also are the most economical methods of generating the gas, and an indication of the quality of chemicals best suited for the purpose.

In connection with this experimental work the scale species themselves are being given a careful study in the field to determine their exact life history as a basis for the intelligent application of the remedy.

This investigation was started in July, 1907, under the field charge of Mr. R. S. Woglum, who first made himself thoroughly familiar with the problem by a personal examination of conditions throughout the citrus-growing regions of southern California. The direct work of investigation began as soon as the fumigation season opened, and later Mr. Frederick Maskew was employed to assist in the work. The experimental work as planned has been conducted on a commercial scale, so that the conditions and results will be those normal to the ordinary care of citrus groves. To carry out all the lines of experiment indicated above, and the subsidiary ones which have developed in the course of the investigation, takes a good deal of time, and will probably occupy two or three years with the money and force now available. Nevertheless, very considerable progress has been made, and the preliminary report herewith submitted covers the general features of fumigation procedure.

Improved methods have been devised, and these are being very rapidly adopted throughout southern California. These improved methods make it possible to do much more uniform work and greatly simplify the method of estimating the proper dosage. Full advantage has been taken of the fumigation work conducted in Florida against the white fly under the field direction of Dr. A. W. Morrill, and the Morrill system of marking tents for the ready determination of dosage has been introduced, with modifications, into California.

C. L. Marlatt,

Entomologist and Acting Chief of Bureau in Absence of Chief.

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INTRODUCTION.

Early in July, 1907, the writer received a commission to investigate the use of hydrocyanic-acid gas in the control of insect pests of citrus trees in southern California. Acting under detailed instructions from Mr. C. L. Marlatt, the Assistant Chief of the Bureau of Entomology of the United States Department of Agriculture, he spent the latter part of July and the following three months in a thorough field investigation to acquaint himself with the conditions of citrus culture throughout southern California, the distribution of the different citrus pests and the damage caused by them, the existing methods for their control, and the status of fumigation as then practiced in the various citrus districts. During this period all the important citrus-producing sections south of Santa Barbara were visited, and local conditions were carefully examined. This work was greatly facilitated by the hearty cooperation of the different county horticultural commissioners, who gave their time freely and greatly assisted the writer in becoming familiar with all the features of the problem in their respective counties.

The writer desires to acknowledge his indebtedness to the many people who have assisted him during this investigation and facilitated the progress which has been made. To Mr. C. L. Marlatt, Assistant Chief of the Bureau of Entomology, he is especially indebted for valuable assistance and advice. It is also the writer's great pleasure to acknowledge his appreciation of the work of Mr. Frederick Maskew, who has most capably assisted him in the performance of many of his experiments. Mr. Maskew also prepared several of the illustrations used. To the Hon. J. W. Jeffrey, State commissioner of horticulture of California, credit is due not only for his activity in paving the way for this investigation but also for the able support given since field work was commenced. To Mr. William Wood, of Whittier, Cal., the writer acknowledges his indebtedness for assistance in introducing the improved system of fumigation in the region adjacent to Whittier, as well as for practical advice with regard to citrus insects and their control, a subject about which he is especially well informed. This occasion is also taken to thank the various horticultural officers of southern California, packing-house managers, and the many citrus growers who have assisted and supported this investigation.

EXTENT OF CITRUS ORCHARDS.[a]

The production of citrus fruits in southern California is confined to the narrow stretch of land south and west of the Sierra Madre Range, extending from Santa Barbara on the north to the Mexican border. Although citrus plantings are located here and there throughout this territory, in reality only a small proportion of the land capable of cultivation is devoted to this industry. The most prominent centers of production (see fig. 1) are in the foothills region and lower land of the San Gabriel Valley; the corresponding regions of the San Bernardino Valley, including the Redlands-Highland, the Riverside, and the Corona districts; and the coast region of Orange

FIG. 1.—Map showing principal localities in southern California where citrus fruits are produced. (Original.)

and Los Angeles counties. Regions of smaller production are found in southern Santa Barbara and Ventura counties, in the San Fernando Valley, and in western San Diego County.

CITRUS PESTS.

INSECT ENEMIES OF CITRUS FRUITS, AND THEIR DISTRIBUTION.

The larger number of the pests most injurious to citrus fruits in southern California belong to the Coccidæ, a group of insects popularly known as scale-insects. Among the scale-insects which are

[a] For a general description of the California citrus-fruit industry, see Bulletin 123, Bureau of Plant Industry, United States Department of Agriculture, which may be obtained for 20 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C.

generally so destructive as to require extended efforts for their control are the purple scale (*Lepidosaphes beckii* Newm.), the red scale (*Chrysomphalus aurantii* Mask.), and the black scale (*Saissetia oleæ* Bern.). The yellow scale (*Chrysomphalus citrinus* Coq.), considered a variety of the red scale, is much less destructive generally, though sufficiently troublesome in some localities to be considered a pest of primary importance. Other scale-insects attacking citrus trees, which are so perfectly held in control by their natural enemies and other causes as seldom to become very destructive, are the soft brown scale (*Coccus hesperidum* L.), the hemispherical scale (*Saissetia hemisphærica* Targ.), the oleander scale (*Aspidiotus hederæ* Val.),

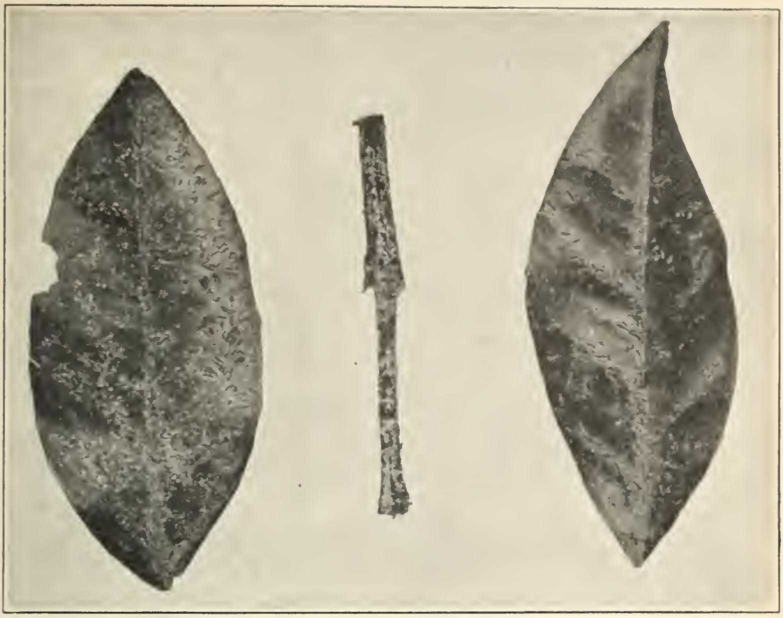

FIG. 2.—Leaves and branch of orange infested with purple scale (*Lepidosaphes beckii*). (Original.)

and the cottony cushion scale (*Icerya purchasi* Mask.). Mealy bugs (*Pseudococcus* spp.) are quite generally prevalent.

The most important pests other than scale-insects are to be found among the mites, of which the rust mite of the orange or silver mite of the lemon (*Phyllocoptes oleivorus* Ashm.) and the citrus red spider (*Tetranychus mytilaspidis* Riley) are highly injurious. The orange aphis (*Aphis gossypii* Glov.) becomes very numerous during some seasons but is soon attacked by its natural enemies and held in control. A species of thrips worked quite extensively in some localities on ripe oranges during the first months of 1908, removing the coloring matter from beneath the epidermis, thus giving to the fruit a spotted appearance which lowered its market grade.

The purple scale (figs. 2 and 3) appears to prefer the more moist regions in the vicinity of the ocean. It is found in Santa Barbara

and Ventura counties; in Los Angeles County, inward from the coast as far as Hollywood and Whittier, and in the lower part of the San Gabriel Valley at Covina and Duarte; throughout Orange County; and in San Diego County in the region about San Diego city. This insect confines its attack to citrus trees.

FIG. 3.—Fruit of orange infested with purple scale. (Original.)

The black scale (fig. 4) is also considered as partial to the more moist regions, and without doubt is able to mature more freely here than in the hot interior country. It is distributed, however, throughout the citrus-growing localities with the exception of the Rialto-Highland-Redlands region of San Bernardino County. At Redlands this scale is found on olives and some ornamental plants; yet, to the best of the writer's knowledge, it has not been reported from citrus orchards. Even as far inland as Ontario and Riverside the black scale is capable of breeding freely during some parts of the year, but the hot days of summer destroy a large percentage of the eggs and especially those young scales which are exposed to the sun's rays. This destruction was especially noticeable in the summer season of 1907, when the writer was engaged in an examination of different localities. During the first part of July occurred a few days of very hot weather. About

FIG. 4.—Branches of orange infested with black scale (*Saissetia oleæ*). (Original.)

a month later inspections were made throughout the lower San Gabriel Valley, at Pomona, Ontario, and Riverside, and in Orange County. Throughout this valley a large majority of the young insects which had hatched were dead at this time while fully 50 per cent of the eggs had dried up. At Pomona, Ontario, and Riverside almost all the young insects had been destroyed, and fully 90 per cent of the eggs beneath the old scales. In Orange County near the coast a very small percentage of eggs was affected by this hot period, while recently hatched young scales were much in evidence. The black scale occurs on a wide range of hosts, including trees, shrubs, and herbaceous plants.

The red scale (fig. 5) thrives exceedingly well in the drier interior regions of southern California. It can be found within a few miles

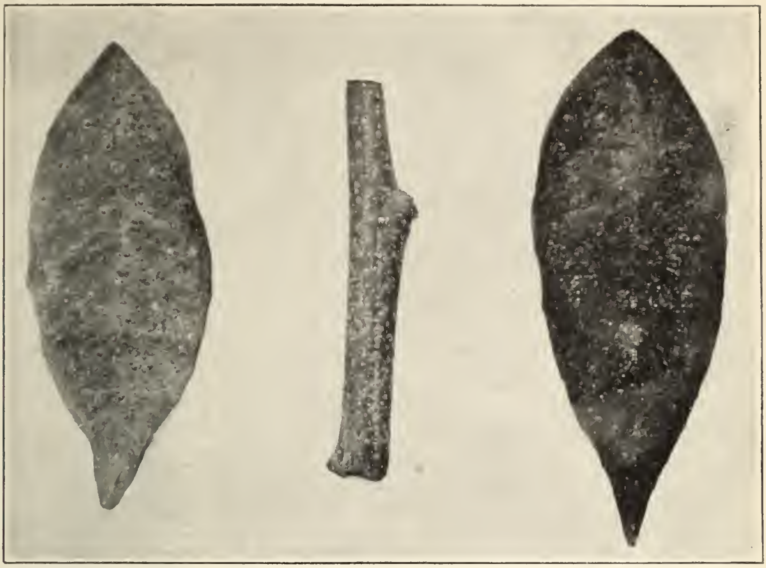

FIG. 5.—Leaves and branch of orange infested with red scale (*Chrysomphalus aurantii*). (Original.)

of the ocean or as far inland as Redlands. The limits of its distribution are much the same as for the black scale. This species can be found on several host plants other than citrus species.

The yellow scale is even more of a heat-withstanding form than the red scale. Infestation by this insect appears to be most marked in the foothills region of the San Gabriel Valley, and along the Sierra Madre Range through Upland and Cucamonga. It is also broadly distributed at Redlands, where it has become a more serious menace than elsewhere in southern California. That it is capable of withstanding excessive heat is demonstrated by its prevalence in citrus orchards in the San Joaquin Valley, at Marysville, Oroville, and other parts of the hot interior valleys of northern California, where the purple scale and to a large extent the black scale appear unable to survive.

Mealy bugs occur in various parts of the southern end of the State. Their appearance is usually spasmodic and in restricted areas. These insects are at present more serious than elsewhere in Ventura County, where they occur in great numbers.

The citrus red spider is general in distribution, whereas the silver mite is restricted to the region about the city of San Diego.

INJURY RESULTING TO SCALE-INFESTED TREES.

In scale insects the mouth is an elongated beak or tube. This tube is inserted into the bark or covering of the host plant when the insect is feeding, and is used to draw up the plant juices, which are the scale-insect's only food. When great numbers of these insects draw sap from the tree, even though they are very minute, the tree's vitality is greatly reduced. This effect is very marked in the attacks of the red and purple scales. Both of these species cause much destruction, yet the writer is of the opinion that the red scale will destroy a citrus tree in less time than will the purple scale, all other factors being equal. Trees have been noticed from two to three years after planting which had been killed by the red scale. Large orchard trees are frequently destroyed by the pest (fig. 6), while it is a very common sight in regions of severe infestation to see large branches killed back to the trunk. Although no trees have ever come to the writer's attention which were completely killed by the purple scale, severe infestations result in the destruction of many branches (fig. 7), and cause such a drain on the tree that the production of fruit is greatly decreased. Moreover, the purple scale spreads

FIG. 6.—Orange tree almost destroyed by red scale. (Original.)

to the fruit, as does also the red scale, resulting in expense for the cleaning of fruit or rendering it of a lower grade and, in extreme cases, entirely valueless.

The black scale, although a much larger insect than either the red scale or purple scale, appears to have, generally, little effect on the vitality of the tree. Trees severely infested with the black scale may appear as healthy as neighboring trees which are clean. Branches are seldom if ever destroyed by its attacks alone.

The commercial importance of the black scale arises largely from its habit of secreting honeydew, which spreads over the leaves, fruit,

FIG. 7.—Orange tree showing branches at center partly destroyed and stripped of leaves by purple scale (*Lepidosaphes beckii*). (Original.)

and branches, furnishing a growing medium for a black or sooty-mold fungus, resulting in a black coating throughout the tree. This coating is removed from the fruit by washing, or in light attacks by brushing. In the investigation by Mr. G. Harold Powell[a] of the causes of decay of oranges while in transit from California, it was shown that the decay was greater in washed than in unwashed fruit. To avoid the washing of fruit it is necessary to destroy the scale in the orchards.

[a] Bul. 123, Bur. Plant Industry, U. S. Dept. of Agriculture, 1908.

The black scale confines its attack mainly to the branches, yet it is commonly found on the leaves during its earlier stages of development and sometimes matures in this situation. Seldom does it mature on the fruit. The red and purple scales infest the branches, leaves, and fruit. The yellow scale occurs on the leaves and fruit. Occasionally it is found to a very slight extent on the branches.

The more directly injurious effect to the tree resulting from the attacks of the red, purple, and yellow scales appears to the writer to be due to their ability to produce some toxic effect in the host plant in addition to the injury caused by the removal of sap. These scales cause a discoloration of the plant cells at the place where the sap is extracted, whereas the larger black scale causes no discoloration whatever.

METHOD OF PROPAGATION OF THE MORE INJURIOUS SCALE PESTS.

The young purple and black scale-insects hatch from eggs deposited by the adult, while the red and yellow scales produce their young alive. The red and yellow scales are thus susceptible to the application of remedial measures at any time throughout the year. The eggs of the purple scale are much more difficult to destroy than the insects, for the latter can be killed readily in any stage of development although more easily in the early stages. The black scale is capable, after it has reached its mature and leathery condition, of resisting extreme insecticidal applications. Its eggs, also, are quite as resistant as the mature insect, if not more so. In its early stages, however, it can be readily destroyed by the proper insecticides.

In all species the different broods on citrus trees are seldom, if ever, distinct, but overlap one another to varying degrees. At certain periods the breeding is more marked than at others for each of these insects; yet it is possible to find adult red, yellow, purple, or black scales in the egg-laying stage at any time throughout the year in any extensive citrus locality in southern California containing thrifty trees and in which these scales are known to thrive. This overlapping of broods is due largely to the forcing and artificial conditions of citrus culture.

METHODS USED IN THE CONTROL OF SCALE PESTS OF CITRUS TREES.

The methods generally resorted to in the control of citrus insect pests are (1) fumigation, (2) spraying, and (3) the use of beneficial insects.

The question of beneficial insects is too large for discussion in this limited report; suffice it to say that their work is of the highest importance in many respects.

Sulphur sprays are employed against the red spider and the silver mite of the lemon.

Distillate sprays have been employed by southern California horticulturists for many years, and at one time very extensively in the control of citrus scales. The accumulated experience with these sprays appears to have demonstrated that the results secured are not entirely satisfactory. To-day distillate sprays are used only on a small acreage of citrus groves, having been supplanted by the more satisfactory fumigation with hydrocyanic-acid gas. Nothing illustrates more distinctly the superiority of fumigation over spraying with distillate oils than the readoption of fumigation by the more successful citrus growers, and the attitude of the officials of the county horticultural commissions of this region who, almost to a man, now recommend fumigation for the control of scale-insects.

A kerosene-water spray has found a limited use during the past year in Riverside and Ventura counties.

FUMIGATION.

Fumigation with hydrocyanic-acid gas originated and was first practiced in California by Mr. D. W. Coquillett, of the Bureau of Entomology, in 1886, in combating citrus insect pests. Since that time it has gradually risen in favor as a means of destroying scale enemies of citrus plants until to-day it is in use in almost all the important citrus-producing countries of the world. The apparatus first used in fumigation was somewhat complicated and cumbersome, making the operation very expensive.[a] As the use of this gas became more widespread a gradual improvement in equipment as well as methods has taken place, so that to-day the process is comparatively simple.

SHEET TENTS.

Sheet tents exclusively are now used in southern California. The manipulation of sheet tents and the general procedure in fumigation have been so clearly explained in Bulletin No. 76 of this Bureau that it will not be necessary to devote space to them here. The tents are octagonal in shape, the standard sizes being 17, 24, 30, 36, 41, 43, 45, 48, 52, 55, and 64 feet, but larger ones up to 72 or 84 feet have been employed. The size of this style tent is properly based on the distance between the parallel sides, not on the distance between opposite corners.

The materials especially recommended, and now generally used for fumigation tents in southern California, are 6½-ounce special drill and 8-ounce special army duck, although 10-ounce special army duck is sometimes used in very large tents. The 6½-ounce special drill is made of single threads twisted hard and closely woven. It is light, strong, and flexible. The special army duck is made of double

[a] See Ann. Rept. U. S. Dept. Agr. for 1887, p. 123, 1888.

threads twisted hard and woven fairly close. This double-twisted material is heavier and much stronger than the special drill, but not so closely woven; consequently it is somewhat more porous. In field work the special drill will adapt itself more closely to the irregularities of the ground than the army duck, and particularly if the tents become damp. The special 6½-ounce drill is generally considered the best obtainable for use in all fumigation tents up to 45 feet standard size. Special 8-ounce army duck is recommended for use in tents of larger size. Probably the most satisfactory method of making large tents is to have the center of special duck and the sides of special drill. This distributes the heavy material at the points of greatest wear, while the drill makes the tent much lighter and more flexible.

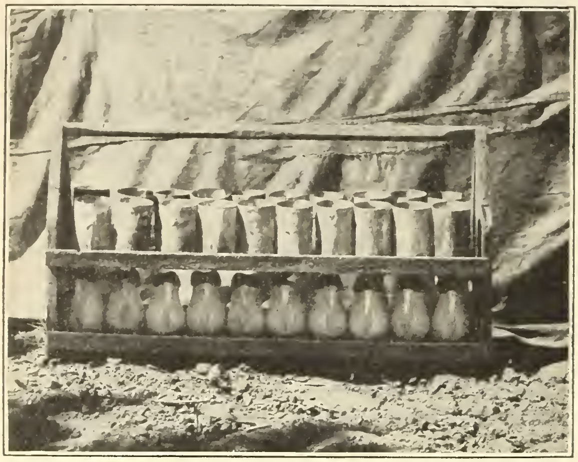

FIG. 8.—Tray commonly used for carrying the chemicals of fumigation from tree to tree. Cans above contain cyanid; pitchers below contain acid. (Original.)

POINTS ON PROCEDURE.

The number of men making up an outfit varies from three to six. In San Bernardino County most of the outfits consist of six men; elsewhere they more commonly consist of four.

In estimating the dosage, the usual method is to make the estimate before the trees are covered with a tent. Sometimes this scheduling is done in the daytime, sometimes by night. The schedule for a row of trees to be fumigated having been given, either one of two methods of procedure is followed. In the first and more common method the dosage of cyanid and acid for each tree of the row is measured out into small cans and pitchers, which are placed in a tray after the manner shown in figure 8. When ready for use this tray is carried from one tree to the next down the row (fig. 9). Frequently two trays are necessary to carry the material required for the entire row or set of trees. The water is carried in a pail and measured at each tree. The receptacles in which the gas is generated consist of earthenware jars holding 1½ to 2 gallons, having the handle on the side (fig. 10). If dosages in excess of 16 ounces are used in a 1½-gallon generator or

in excess of 20 ounces in a 2-gallon generator, the contents will frequently boil over, especially if the cyanid is in small lumps or is powdered.

DOSAGE SCHEDULES OF THE MORE IMPORTANT WRITERS ON FUMIGATION.

Since the publication by Morse, in 1887, of the first dosage schedule for use in fumigating citrus trees with hydrocyanic-acid gas, a great many tables of dosage have been recommended through publications in this country and abroad. Among the more authoritative contributions on this subject are those of Coquillett, Morse, Craw, Marlatt, Johnson, Havens, Woodworth, Pease, and Morrill, of this country; C. P. Lounsbury, of South Africa, and W. J. Allen, of New South Wales. A careful study has been made of the dosage schedules proposed by these different investigators with a result most surprising. In the first place, we must consider that uniform dosage will not be given to trees unless based directly on their cubic contents when covered with a tent. Secondly, dosage tables prepared for trees merely with regard to their cubic contents and without regard to the varying proportions of leakage surface present in trees of different sizes are faulty to a large degree. Of all the dosage tables which have come to the writer's attention only those by Lounsbury, in South Africa, by Morrill, in Florida, and a recent one by Woodworth in California, have been based on the proper assumptions. The other tables were either based directly on the cubic contents without regard to leakage surface, or were prepared without any knowledge whatever of the cubic contents represented by trees of given dimensions. Several

FIG. 9.—Man carrying tray and water bucket. (Original.)

belong to the latter class. The following statement and comparative table have been prepared which indicate the wide range of variation in these schedules:

Dosage schedules.—For the information of those who may be inclined to doubt the writer's contentions in this bulletin with relation to the generally chaotic condition of fumigation schedules published in the interests of California citrus growers, a table has been prepared which includes nearly all of the more important schedules, together with a comparative analysis of the same. The dosages for trees of given dimensions were duly computed. Having this data at hand and utilizing the dosage allotted to each individual tree, it was possible to work out the rate of

FIG. 10.—A typical California lemon orchard with row of fumigation generators placed ready for use the following night. (Original.)

dosage per 100 cubic feet of inclosed space at which that particular tree was being fumigated. This has been done for all trees in the schedules proposed by several writers, and the results have been arranged in the latter half of the table.

A glance at this table will show that the schedules of Morse, Coquillett, and Woodworth were all based on the cubic contents of the trees, which were dosed at a uniform rate, but without regard to the leakage of gas. Large trees are dosed at the same rate as small ones, thus giving a lack of uniformity in results. All of the other schedules detailed in this table were apparently prepared with little or no regard to the cubic contents represented by trees of different dimensions. Although it would appear from the table that leakage was taken into account, inasmuch as the smaller trees receive a greater rate than the larger ones, proper allowance could not be made for this factor without definite consideration of the cubic contents. Consequently the decrease of rate recommended is in all cases irregular and widely removed from a rate proportionate to the actual leakage. The fact that trees in-

crease in dimensions much more rapidly than in cubic contents is seldom taken into consideration. The result is that the larger trees receive a relatively smaller dosage than they should.

Morse's schedule was prepared especially for the cottony cushion scale and probably for the red scale. The schedules of Coquillett and Pease, and doubtless that of Craw, were prepared for the red scale. Those of Johnson, Woodworth, the Riverside Commission, and the Rural Californian were intended especially for use against the black scale. The red scale was generally known to be harder to destroy than the black scale.

In Morse's schedule all trees receive practically three-fourths ounce per 100 cubic feet of inclosed tent space; in Coquillett's, practically one-half ounce to 100 cubic feet; in Woodworth's schedule they receive one-third ounce for the same space. In Craw's table, the smallest tree receives approximately 9 times as great a dosage rate as the largest; in Johnson's table, the smallest receives about 4½ times the rate of the largest; in that of the Riverside Commission, the smallest is allowed about 13 times that of the largest; in that of the Rural Californian, the smallest receives about 8 times that of the largest; while in that of Pease, the smallest receives a dosage rate about 14½ times as great as the largest tree.

This short analysis seems sufficient to call attention to the irregularities of these schedules. A study of the following table will reveal many other interesting points.

Dosage schedules recommended by several recognized authorities, with computed dosage rates per 100 cubic feet of space inclosed by tent.

AMOUNT OF CYANID (OUNCES) PER TREE RECOMMENDED.

Height of tree.	Width of tree.	Cubic contents of tree.	Morse.[a]	Coquillett.[b]	Craw.[c]	T. B. Johnson.[d]	Woodworth.[e]	Riverside Horticultural Commission.[f]	Rural Californian.[g]	Pease.[h]
Feet.	*Feet.*	*Cubic ft.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*
4	4	40	0.3							
4	5	60								4
5	5	80	.6							
6	4	70			1	1		1	½	
6	5	100								4
6	6	140	1				½			5
7	7	225	1.6							
8	5⅓	160					½			
8	6	200			2	2		1½	1¼	5
8	8	335	2.4				1			7
9	9	475	3.4							
10	6⅔	310					1			
10	8	435		2¼	3	3½		2½	2	7
10	10	645	4.6			4½	2			8
11	11	870	6.2							
12	8	535					2			
12	10	800		4½	5	5			4½	8
12	12	1,130	8				4			10
12	14	1,490		8¾	7	7		5	4½	
13	13	1,440	10.2							
14	10	960		5½						
14	12	1,355		7½		7				10
14	14	1,790	12.4		8	8			5	12
15	10	1,036					4			
15	15	2,210	15.7				8			
16	14	2,105		12		9				12
16	16	2,680	19		9	10⅓		8	5½	14
17	17	3,215	23							
18	14	2,400		15						
18	16	3,080			10				6	14
18	18	3,815	27.1							
19	19	4,470	28.3				16			
20	13⅓	2,475					8			
20	16	3,485			11	13		10	6½	
20	18	4,325				15		14		
20	20	5,235	36.2					10		
20	22	6,210						14		
22	18	4,835			12				7¼	

[a] Bul. 71, Univ. of Cal. Agr. Exp. Sta. (1887).
[b] Insect Life (1889).
[c] Destructive Insects (1891).
[d] Cal. State Bd. of Horticulture (1896).
[e] Bul. 115, Univ. of Cal. Agr. Exp. Sta. (1896).
[f] Farmers' Bul. 127, U. S. Dept. Agric.
[g] From "Fumigation Methods," by W. G. Johnson.
[h] California Cultivator (1908).

Dosage schedules recommended by several recognized authorities, with computed dosage rates per 100 cubic feet of space inclosed by tent—Continued.

AMOUNT OF CYANID (OUNCES) PER TREE RECOMMENDED—Continued.

Height of tree.	Width of tree.	Cubic contents of tree.	Morse.	Coquillett.	Craw.	T. B. Johnson.	Woodworth.	Riverside Horticultural Commission.	Rural Californian.	Pease.
Feet.	*Feet.*	*Cubic ft.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*
24	18	5,340				18		14		
24	20	6,490			13	20		16	8	
24	22	7,735						14		
24	28	11,900						16		
26	20	7,120			13½				8¼	
30	20	8,375			14			16	8½	
30	25	12,680						24		
30	28	14,365						16		
30	30	16,675						24		
36	25	15,630						24		
36	30	21,915						24		

COMPUTED DOSAGE RATE (OUNCES OF CYANID) PER 100 CUBIC FEET OF INCLOSED SPACE.

Height of tree.	Width of tree.	Cubic contents of tree.	Morse.	Coquillett.	Craw.	T. B. Johnson.	Woodworth.	Riverside Horticultural Commission.	Rural Californian.	Pease.
Feet.	*Feet.*	*Cubic ft.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*	*Ounces.*
4	4	40	0.75							
4	5	60								6.6
5	5	80	.75							
6	4	70			1.4	1.4		1.4	0.77	
6	5	100								4
6	6	140	.72				0.36			3.6
7	7	225	.71							
8	5⅓	160					.31			
8	6	200			1	1		.75	.63	2.5
8	8	335	.72				.3			2.1
9	9	475	.72							
10	6⅔	310					.32			
10	8	435		0.50	.76	.8		.57	.46	1.6
10	10	645	.72			.7	.31			1.25
11	11	870	.7							
12	8	535					.37			
12	10	800		.56	.62	.62			.56	1
12	12	1,130	.71				.35			.88
12	14	1,490		.58	.57	.47		.33	.3	
13	13	1,440	.71							
14	10	960		.58						
14	12	1,355		.56		.51				.74
14	14	1,790	.7		.45	.45			.28	.67
15	10	1,036					.38			
15	15	2,210	.71				.36			
16	14	2,105		.57		.43				.57
16	16	2,680	.71		.34	.38		.3	.21	52
17	17	3,215	.71							
18	14	2,400								
18	16	3,080			.32				.2	.45
18	18	3,815	.71							
19	19	4,470	.63				.36			
20	13⅓	2,475					.32			
20	16	3,485			.31	.37		.29	.19	
20	18	4,325				.35		.32		
20	20	5,235	.78					.19		
20	22	6,210						.22		
22	18	4,835			.25				.15	
24	18	5,340				.34		.26		
24	20	6,490			.20	.31		.25	.12	
24	22	7,735						.18		
24	28	11,900						.13		
26	20	7,120			.19				.12	
30	20	8,375			.17			.19	.1	
30	25	12,680						.19		
30	28	14,365						.11		
30	30	16,675						.14		
36	25	15,630						.15		
36	30	21,915						.11		

THE PRESENT SYSTEM OF SCHEDULING DOSAGE.

When we understand that up to the present time only one approximately accurate dosage schedule has been proposed by the fumigation experts of California, and, what is more confusing, that no two tables agree in all respects, we can not wonder that the practical fumigator has turned from them in perplexity. Finding the tables of little assistance, the fumigator has had to determine his own dosage from practical experience and the results secured. If he failed to destroy the scale on a 6-foot tree in using 1 ounce of cyanid, he increased his dosage for the next 6-foot tree, and so on. He has also learned that the dosage required to destroy some scales is greater than that for other species. Under the system at present in vogue the dosage is usually estimated in the daytime. The estimator, who ordinarily is the man in charge of the outfit, starts out in an orchard equipped with cross-section paper or a schedule sheet. He walks between two rows of trees, jotting down in the corresponding squares of the schedule sheet the dosage which he believes the trees should receive. If he is a careful scheduler he will look at the trees from different sides before indicating the dosage, as trees are sometimes more compact on one side than on another. Less careful men set down the dosage for the two rows of trees while moving along as fast as they can walk. The writer has seen some schedulers walk through the field at a rapid pace, taking four rows at a time.

The estimation of dosage in this manner is mainly guesswork. Measurements of the trees are made by the eye; consequently, successful results depend very largely upon the accuracy of the estimator's eye-measurement, supported by his experience in fumigation. The most careful of estimators are very irregular in their scheduling. This point has already been mentioned by Professor Woodworth.[a] From measurements taken after many fumigators, we have found none who did not at times vary more than 50 per cent in dosage estimates for trees containing exactly the same cubic contents after being covered with a tent. Frequently the variation is as high as 100 per cent. The results secured by a few of the more careful and expert schedulers have been good as a whole. These men, however, can cover but a small portion of the citrus groves of southern California in one season.

The writer has been shown orchards in which it was stated that all the scale had been destroyed by the use of heavy dosages. Even if this were the case it would show that the smallest percentage or strength of dosage used on any tree in those orchards was sufficiently large to destroy the scale. Since, as we have found, expert fumigators

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[a] Bul. 152, Univ. of Cal. Agr. Exp. Sta., 1903.

vary considerably in their estimates, many trees in the above-mentioned orchards must have received a much greater dosage than was necessary for scale eradication, thus resulting in a waste of cyanid and acid.

In Table I have been arranged the dosage estimates which were scheduled in different orchards by three different fumigators. After the trees had been covered with tents the exact contents were computed by the writer from actual measurements. The dosages given in these tables are not for scattered individual trees selected because of their irregularity in size, but each table embraces a continuous number in a single row taken at random, regardless of the size or regularity of the trees. As great a lack of uniformity as that shown in each table might be looked for throughout the orchard. These schedules of dosage were used against the red and purple scales, species considered by most fumigators to be about equally resistant to the gas. The reader will note the wide difference in the dosage in the estimates of the different fumigators.

Table I.—*Variation in the dosages estimated for several consecutive trees by three different fumigators.*

Work of first fumigator.			Work of second fumigator.			Work of third fumigator.		
Dosage recommended.	Actual volume of treated tree.	Volume of space in tent to each ounce of dosage.	Dosage recommended.	Actual volume of treated tree.	Volume of space in tent to each ounce of dosage.	Dosage recommended.	Actual volume of treated tree.	Volume of space in tent to each ounce of dosage.
Ounces.	*Cubic feet.*	*Cubic feet.*	*Ounces.*	*Cubic feet.*	*Cubic feet.*	*Ounces.*	*Cubic feet.*	*Cubic feet.*
11	1,690	150	11	1,000	90	6	1,500	250
12	2,050	170	7	400	60	4	1,100	275
10	1,369	135	15	1,800	120	4	800	200
10	1,663	165	10	600	60	5	1,200	240
10	1,516	150	16	2,200	140	4	1,100	275
12	1,440	120	15	1,800	120	4	900	225
12	1,663	140	16	2,400	150	5	1,300	260
12	1,755	145	16	2,000	125	5	1,150	230
12	1,350	110	18	2,200	120	5	950	190
9	1,175	130	17	2,200	130	4	950	238
....	....	....	12	1,250	105	5	900	180
....	....	....	16	2,500	156	6	1,550	258

THE INITIAL PROBLEM CONFRONTING THIS INVESTIGATION.

After becoming acquainted with the existing methods of fumigation, it was realized that one of the first problems to be solved was to devise some accurate system of determining dosage which would obviate the errors due to guesswork. It at once became apparent that the only way in which this result could be attained was by determining accurately the cubic contents of the space inclosed by the tent and giving the tree a dose proportionate to the contents. It was also apparent that before such a system could be put into operation, after having been worked out in practice, it would be

necessary to determine by an extensive series of experiments the dosage required for different-sized trees for the various scale pests infesting the citrus orchards.

METHOD OF COMPUTING VOLUME AND DOSAGE FOR TENTED TREES.

Although most citrus trees possess a certain general similarity in shape, they are nevertheless somewhat irregular, no two ever being identical in all respects. This renders it impracticable to determine the exact contents of any given tree. For field work, however, this is unnecessary, and all that is needed is to approximate it with a fair degree of accuracy. In order to calculate the cubic contents of an object, it must be considered as shaped like some regular geometrical figure or figures. The figure which most closely approximates in shape an orange or lemon tree before it has been pruned is a cylinder surmounted by a hemisphere, and in computing the volume we have considered them of this shape.

If we know the height and width of a tree covered with a tent, it is a comparatively simple matter to calculate its contents.

In the past in California work the dosage has been based upon these two measurements. After a tree is covered with a tent it is a matter of some difficulty to determine the height and the width. By using as factors the distance around the bottom of the tent and the longest distance over the top of the tent we arrive at a more practicable method by which to compute the cubic contents of a given tree. Using these measurements as a basis the writer has invented a formula [a] by means of which the cubic contents of a tree may be computed. To avoid computation work in the field as far as possible, the writer has formulated a table approximating the cubic contents of trees of different dimensions, which is, he believes, sufficiently extensive to include any citrus tree in southern California. During this investigation no tree has been found whose dimensions did not fall within the limits given in this table. The distance

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[a] Professor Woodworth (Bul. 152, Univ. of Cal. Agr. Exp. Sta., p. 5, 1903) was the first to propose a formula for obtaining the contents of tented trees by computing the distance around the bottom and over the top. An analysis of this formula during the early part of the writer's field work proved that it was inaccurate, thus necessitating the determination of a new formula. The writer has worked out a formula based on the two measurements above mentioned. It is as follows:

$$\frac{C^2}{4\pi}\left(\frac{O}{2}-\frac{C(3\pi-4)}{12\pi}\right)$$

In this formula C=the circumference of the tree.
O=the distance over the top of the tree.

If a person works out and notes down in a chart the values of $\frac{C^2}{4\pi}$ and $\frac{C(3\pi-4)}{12\pi}$ for different values of C of which he is apt to make common use, it is possible by its use in connection with the formula to determine the contents of trees with fair rapidity.

around and over a given tree being known, the table will show the approximate cubic contents of the tented tree. The dosage can then be applied in proportion to the contents and at any strength desired.

A lemon tree, after being pruned, is flat on the top. Therefore we can not consider the geometrical figure which is applicable to an orange or unpruned lemon tree as also applicable to a pruned or flat-topped lemon tree. The figure which approximates the latter is a cylinder. Now it so happens that the contents of a cylinder having certain dimensions over its top and around its bottom are almost the same as for a figure of the same dimensions composed of a cylinder surmounted by a hemisphere. This is a great advantage inasmuch as the schedule of dosage proposed for orange trees may also be used for all lemon trees, thus obviating the necessity of preparing two different schedules.

METHODS FOR OBTAINING THE MEASUREMENTS AND DOSAGE OF TREES.

WITH APPARATUS.

Of the various methods suggested for obtaining the measurements of tented trees, the first was naturally by the use of a tapeline. It was an easy matter to ascertain the distance around the tent with a tape, but to measure the distance over the top was much more difficult. This required the services of two men and repeated efforts. For field work on a commercial scale this was impracticable.

Woodworth[a] explains a method of securing measurements, which consists in the use of a fishing rod and a wire line, the latter marked off by knots into 1-meter lengths. His description of this method is as follows:

> Having first attached the line at about its middle to the end of the rod, one end of the former is made fast to the tent. The most convenient way to accomplish this was found to be by means of a hook, like a fishhook from which the barb had been removed. The most convenient place of attachment was at a point 1 meter from the ground.
>
> After attaching one end of the line to the tent the rest of that half is caused to lie up to and over the center and top of the tent by means of the rod. The one making the measurement then walks around to the opposite side of the tent, rod in hand, holding the line constantly in position over the top. The other end of the line is carried around the tent at the same time and is then drawn taut, measuring the last fraction of a meter by means of the graduation on the lower joint of the rod. Adding now 1 meter, the distance the first end is from the ground, we have the measurement of the distance over the top of the tent from the ground on one side to the ground on the other.
>
> A second measurement was then taken by throwing the line off the top of the tent by means of the rod and holding it so that as the measurer proceeds around the tent to the point where the line is attached, it will encircle the tent at a point about 1 meter from the ground. The end of the rod is again brought into requisition and the last fraction of meter read in centimeters.
>
> Both measurements are thus made by one person in a single trip around the tent.

[a] Bul. 152, Univ. of Cal. Agr. Exp. Sta., 1903.

This method might be practicable with a medium-sized tree, but for trees of large size, especially seedlings, which are sometimes more than 30 feet in height, its use would doubtless prove difficult, and for field operations multiplication of apparatus should be avoided as far as possible.

WITHOUT APPARATUS.

The Woodworth system.—The first scheme, so far as the writer's knowledge goes, for obtaining the measurements and dosage of trees without the use of apparatus was suggested by Professor Woodworth.[a] This method consists of marking on the tent, on two opposite sides and parallel with the edge, a series of lines which are placed at such distances from the center of the tent that they will correspond with differences of 1 ounce in the dosage of trees of the average shape. Upon each of these lines are marked three numbers; the first indicating the dose (in ounces), the second the circumference on which the dose is based, and the third the amount the dose must be varied when the actual measured circumference is greater or less than that marked on the tent. For trees having a circumference greater than the average between the second figure on the line that is nearest the ground on one side of the tent and the second figure on the corresponding line on the opposite side, the average dose is increased for each additional yard of circumference by the amount (in ounces) given by the third figure on the line; for trees having smaller circumferences the figures are correspondingly decreased.

Although the system is fairly accurate, its adaptability for use under the present condition of fumigation in southern California is somewhat questionable. The amount of calculation required to ascertain the dosage for each tree gives large chance of error and is wasteful of time. The possibility of error is still further increased through the necessity of varying the dosage for different species of scale-insects.

The Morrill system.[b]—Dr. A. W. Morrill, in the course of his work against the white fly (*Aleyrodes citri* R. & H.) in Florida, has devised a method of marking tents which is easily the most practicable yet proposed for obtaining the distance over the top of a tented tree. Although apparently a modification of the idea presented in the Woodworth method, it is really quite different. In the Woodworth system the actual dosage is calculated from the figures on the tent. The Morrill system is merely a rapid and simple way of obtaining the distance over the top of a tented tree.

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[a] Bul. 152, Univ. of Cal. Agr. Exp. Sta., 1903.

[b] Bul. 76, Bur. Ent. U. S. Dept. Agr., 1908.

In figure 11 is shown an outline of a regulation fumigating tent marked after the Morrill system. Three parallel lines and one line at right angles to them are indicated on the tent. The middle one of the three parallel lines passes through the central point in the tent canvas, running lengthwise of the central section or strip of which the tent is made and passing over the top of the tent from the edge on one side to the edge on the opposite side; these lines

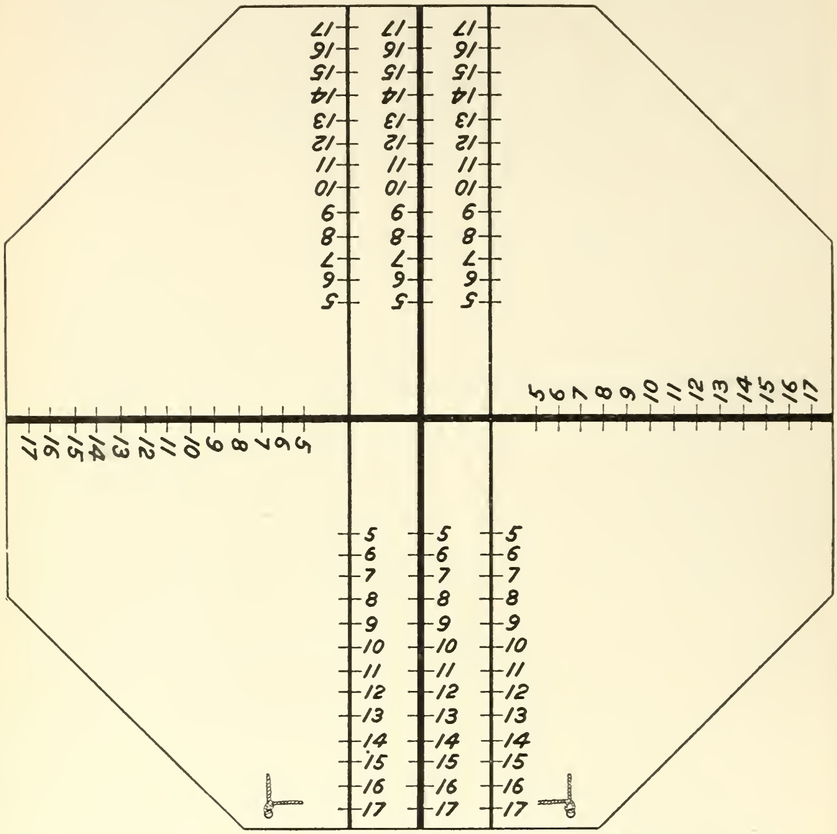

FIG. 11.—Outline of a fumigation tent marked according to the Morrill system.

also run in the direction in which the tent should be pulled on or off a tree. The single line at right angles to the parallel lines passes through the central point, as does the middle one of the three parallel lines, and extends also from the edge on one side to the edge on the opposite side. Beginning at the center these lines are graduated in feet toward either edge of the tent, after the manner shown in the diagram. For tents above 36 feet (average size) it is unnecessary to commence the graduation nearer than 5 feet from the center of the canvas. When one of these lines is over the middle of the tree

(fig. 12), the distance over can be calculated by merely adding together the two numbers on the opposite sides of the tent where the edge touches the ground. For instance, suppose that on the line over the center of the tree 12 is nearest the ground on one side and 15 on the other. The distance over the center of this tree would be the sum of these numbers, which is 27 feet. With the lines graduated after this manner it makes little difference in determining the distance over the top of the tree whether or not the geometrical center of the tent is at the center of the tree, the single requirement being that some part of one of the graduated lines approximates the center of the tree.

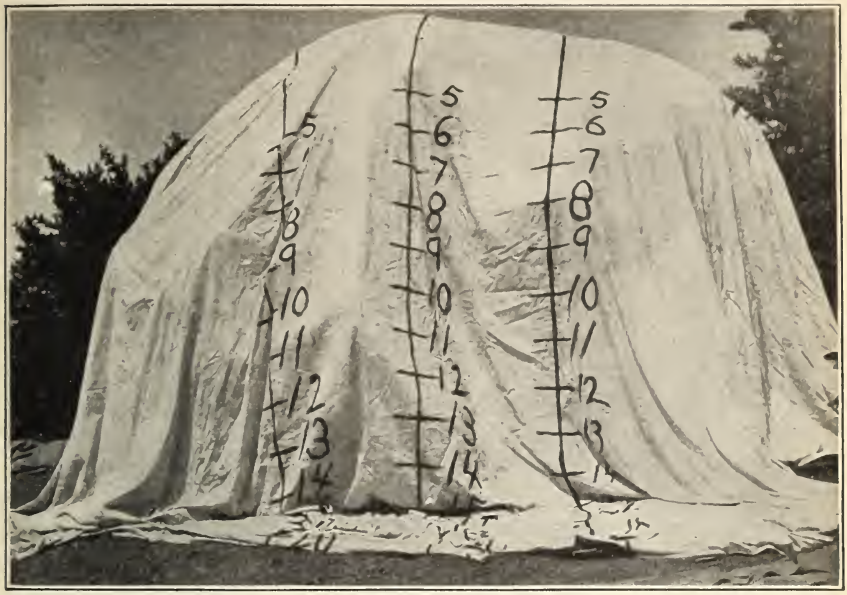

FIG. 12.—A fumigation tent marked after the Morrill system. (Original.)

The two lines running parallel to this central line should be about 4 feet distant from it in the larger fumigating tents. The reason for using these auxiliary lines is, that in practice the center of the tent is very often pulled considerably to one side, especially in covering small trees. If the middle line does not fall immediately over the center of the tree, one of the other two lines is quite likely to do so, and that one should be used in obtaining the distance over.

The cross line running at right angles to the three parallel lines also passes through the center of the tent and is marked like the others. In case of an irregularly shaped tree, by the use of this line the distance over can be taken in two different directions and the average taken for use in determining the cubic contents. In field work, however, this cross line is unnecessary, as measurement over the top in one direction is sufficient.

The measurement around the bottom of the tent can be obtained by the use of a tapeline or by pacing. Under this system the work is facilitated by having a chart or table of figures showing the cubic contents corresponding to different dimensions.

THE CHEMICALS REQUIRED IN FUMIGATION.

For the generation of hydrocyanic-acid gas in fumigating, potassium cyanid, sulphuric acid, and water are necessary. The hydrocyanic-acid gas is produced by the action of the sulphuric acid on the cyanid of potassium. Under the early methods of generating hydrocyanic-acid gas the cyanid was dissolved in water before being used. At the present time cyanid is used in the crystal form entirely. The water is first measured out and poured into the generating vessel. The required amount of acid is then added to the water, producing a great increase in the temperature of the mixture. While the mixture is hot it should be placed beneath the tree and the cyanid added. If permitted to cool before the cyanid is added, the generation of gas will not only be slower than with the heated mixture, but the amount of available gas will be decreased, thus making the operation more expensive, and necessarily less efficient.

POTASSIUM CYANID.

An imported cyanid designated as 98 to 99 per cent pure is used almost exclusively for fumigation purposes in southern California, under the popular belief that it is superior to American cyanids for this purpose. There seems to be no real basis for this common belief, and, in fact, experiments conducted by Prof. Wilmon Newell while State entomologist of Georgia demonstrated that certain brands of American cyanid met all the requirements necessary for fumigating nursery stock, and it seems reasonable to believe that these will also be equally available for citrus-orchard fumigation. A series of laboratory and field tests has been planned to demonstrate the usefulness of all the available brands of potassium cyanid.

In the field investigation reported in this bulletin the 98 to 99 per cent imported cyanid commonly used in southern California has been employed throughout and, although no chemical analysis was made, the results proved entirely satisfactory.

SULPHURIC ACID.

Too much stress can not be placed upon the quality of sulphuric acid used in fumigation. Operators have repeatedly informed the writer of much burning of fruit and foliage which occurred during the season of 1905, owing to the use of a grade of acid differing from that ordinarily employed. An analysis of the acid used that season

showed that it contained traces of nitric acid, the presence of which might explain the burning. Nitric acid is one of the most active of chemicals and is unstable as well. When heated it readily volatilizes. By adding sulphuric acid to water a great amount of heat results. If nitric acid be present in the sulphuric acid as an impurity it would be far more volatile than under ordinary circumstances. The addition of the cyanid increases the heat, at the same time causing hydrocyanic-acid gas to be violently thrown off. This gas assists in carrying off the volatilized nitric acid, which, condensing on the cool, moist surfaces presented by the fruit and leaves of the citrus trees, might result in burns or pits.

In procuring sulphuric acid for fumigating purposes, only that should be purchased which is entirely free of nitric acid, and which is guaranteed 66° (Baumé), or 93 per cent pure.

Some commercial sulphuric acid on the market meets all the requirements of fumigation, while much can be found which does not. To enter fully into the reason for this would be out of place in this bulletin. All that is necessary is to mention briefly the character of the material and processes used by various manufacturers, some of whom strive to place a better grade of acid on the market than do many others.

In the manufacture of sulphuric acid, sulphur may be considered the basic element. This is obtained from one of two sources, viz, from free sulphur, known commercially as brimstone, or from sulphur in combination with a metal, as iron or copper pyrites. Brimstone is comparatively pure sulphur, containing little or nothing which would reduce the grade of the acid manufactured from it. It sometimes contains a very small quantity of ash. Pure iron pyrites contains about 53 per cent of sulphur and about 47 per cent of iron. Copper pyrites contains much less sulphur. Ordinarily the pyrites used in making acid contains small quantities of other elements, as arsenic, zinc, lead, etc. To manufacture sulphuric acid, it is necessary to convert the sulphur into a gas, sulphur dioxid, which is brought about by burning the crude product in a retort. The sulphur dioxid thus formed is conducted into certain chambers where it is mixed with fumes of nitric acid, air, and steam, the resulting product being dilute sulphuric acid. Where brimstone is used comparatively pure sulphuric acid is formed. When, however, pyrites are burned, other elements present in the ore (as arsenic, etc.) are volatilized, pass along with the sulphur dioxid, and are present in the crude acid.

That which concerns us most vitally in fumigating is the presence of nitric acid. A much greater proportion of nitric acid becomes mixed with the products of combustion from pyrites than from brimstone, resulting in the presence of a larger amount of this undesirable

acid in the sulphuric acid. The impurities, including nitric acid, may be eliminated by refining. This, however, requires extra expense, and, as these impurities are of little or no importance in some of the lower uses to which sulphuric acid is put, the acid is not usually refined. Such acid is unsuitable for use in fumigation.

Taking all things into consideration it is safer, in purchasing ordinary commercial sulphuric acid on the market, to order that made from brimstone rather than that made from pyrites ore. It is possible, however, to secure quite as good a product from pyrites as from brimstone, if the former be sufficiently refined. If the fumigator demands that it be free from nitric acid, arsenic, etc., and refuses to accept it unless the product is of the grade required, there is no reason why he should not be able to secure satisfactory material.

PROPORTION OF MATERIALS USED BY FUMIGATORS.

With each dry ounce of potassium cyanid most fumigators use 1 fluid ounce of sulphuric acid, although some use $1\frac{1}{4}$ ounces. The proportion of water used varies all the way from 2 to 8 times the amount (by bulk) of acid, the majority using between 3 and 4 parts of water.

THE AMOUNT OF SULPHURIC ACID NECESSARY.

Chemical combinations take place with definiteness; that is, when one chemical acts on another in the production of a third substance, the proportion between the first two chemicals is always the same. Such is the case when sulphuric acid acts upon potassium cyanid in producing hydrocyanic-acid gas. A given amount of cyanid requires a certain amount of sulphuric acid of a fixed degree of purity to carry the reaction to completion. A quotation from a letter received from J. K. Haywood, of the Bureau of Chemistry of this Department, illustrates this point:

> In the action of sulphuric acid on potassium cyanid approximately four-fifths of an ounce (avoirdupois) of 93 per cent acid is used up for every ounce of 98 per cent cyanid.[a]
>
> Expressed in fluid ounces four-fifths of an ounce avoirdupois equals about 0.42 of a fluid ounce. We may say that theoretically 1 ounce avoirdupois of 98 per cent potassium cyanid needs 0.42 of a fluid ounce of ordinary commercial sulphuric acid (93 per cent) to convert it entirely to hydrocyanic acid. Since it is always best to have some excess of the acid to carry the reaction to completion, it is probable that three-fourths of a fluid ounce of commercial sulphuric acid is ample in practice to convert 1 ounce avoirdupois of 98 per cent potassium cyanid to hydrocyanic acid. If 1 fluid ounce of the commercial sulphuric acid is used it will certainly leave a con-

[a] The reaction is as follows:

$$2KCN+H_2SO_4=K_2SO_4+2HCN.$$

siderable excess of sulphuric acid present. It is perfectly possible, however, that this excess of sulphuric acid is of value in heating up the mixture so that more of the hydrocyanic acid is liberated and not absorbed by the liquid.[a]

The results of some tests serve as a further illustration of this point. It was desired to determine by experiment if 1 fluid ounce of acid to each ounce (avoirdupois) of cyanid would be sufficient to carry the reaction to completion in the liberation of hydrocyanic-acid gas. It is to be understood throughout that the cyanid ounce is avoirdupois and the acid and water is the fluid ounce. For this test two series of ordinary 1½-gallon fumigating vessels were placed in line. In one series equal parts of acid and cyanid were used. Three parts of water were used in all cases. The amounts of cyanid used ranged from 1 to 10 ounces, that is, in one generator were placed 1 ounce of cyanid, 1 ounce of sulphuric acid, and 3 ounces of water; in the next of the same series, 2 ounces of cyanid, 2 ounces of sulphuric acid, and 6 ounces of water, and so on in the same proportion up to 10 ounces. The second series was identical with the first except for the use of one-fourth more acid than cyanid. After generation had taken place for about one and one-half hours an examination was made of the residue. In the first series, in which equal parts of acid and cyanid were used, the residue was in the form of a liquid. In the second series, in which 1¼ ounces of acid to 1 of cyanid were used, the residue in several pots had collected in a mushlike mass. Being puzzled at first over this phenomenon, in order to ascertain if cyanid still remained unchanged in the residue the writer added more sulphuric acid, but there was no further evolution of gas. This at once demonstrated that all the available cyanid had been dissolved. Analyses of this residue by J. K. Haywood of the Bureau of Chemistry showed that the reaction was complete both when 1 ounce of acid and when 1¼ ounces of acid to 1 of cyanid were used. In submitting the result of these analyses, Dr. H. W. Wiley, Chief of the Bureau of Chemistry, wrote:

> The amount of cyanid present in these samples is so small that it does not indicate to us incompleteness of reaction, but rather indicates the amount of hydrocyanic acid dissolved in the residue. This view of the case is strengthened by the fact that increasing the amount of sulphuric acid in the cases above did not decrease the amount of cyanogen present in the residue. From our work, therefore, we are of the opinion that the same amount of sulphuric acid as of potassium cyanid is sufficient to carry the reaction to completion.

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[a] In an address printed in the Proceedings of the Thirty-fourth Annual Fruit Growers' Convention of California, p. 103, the proportion of chemicals spoken of appears somewhat different from that mentioned in this publication. This is due to the fact that the parts mentioned in that address were based on parts by weight of acid and cyanid, both of which are chemically pure—not the commercial product as given in this bulletin.

Summing up, it may be said that 1 fluid ounce of commercial sulphuric acid (93 per cent) to 1 ounce (avoirdupois) of 98 per cent potassium cyanid is certainly enough to carry the reaction to completion in the liberation of hydrocyanic-acid gas and is perhaps an unnecessarily large amount. In practical field work where dosages of varying sizes are constantly being used, it is very convenient to reckon the acid in the same number of parts as the cyanid. The use of 1 part (fluid measure) of acid to each part of cyanid is therefore recommended.

The commercial potassium cyanid sold on the market is usually 96 to 100 per cent pure. The commercial sulphuric acid on the market is sold as 66° Baumé and should contain 93.5 per cent sulphuric acid. In California fumigation work, these grades are used and are to be understood wherever cyanid or acid is mentioned in this bulletin. In the dosage allotments cyanid is always measured in ounces or parts dry weight, while the acid is measured in fluid ounces or parts.

THE EFFECT OF TOO GREAT AN EXCESS OF ACID.

In the experiment mentioned, in which two series of hydrocyanic-acid gas generations were completed, the question immediately arose, why the residue in some generators, in which $1\frac{1}{4}$ parts of acid were used, congealed, while in the case of those in which equal parts of acid and cyanid were used no such result was noted. The explanation is simple: When sulphuric acid acts on potassium cyanid, hydrocyanic acid, a gas, and potassium sulphate, a solid, are formed. If sufficient water is present, the potassium sulphate dissolves and there is no solid residue. This was the result when equal parts of acid and cyanid were used. When one-fourth more acid than cyanid is employed, there is a large excess of acid. The potassium sulphate is not as soluble in water containing excess acid as it is in water alone; hence it undergoes partial crystallization, resulting in a mushlike residue or congealing into a solid mass.

WATER AS A FACTOR IN FUMIGATION.

There are several reasons why water should always be employed in fumigation: It is very useful in dissolving the potassium cyanid and hastening and completing the chemical reaction with the acid. A piece of cyanid thrown into a mixture of acid and water immediately gives up a portion of its mass in solution. Scarcely has the cyanid dissolved when it is partially converted into gas. The heat liberated during this process assists in forcing the solution of more cyanid, which is also partially converted into gas. This continues until the chemicals are exhausted and the reaction stops.

Potassium sulphate, a solid, is the by-product resulting from the reaction by which hydrocyanic-acid gas is produced. Water dis-

solves the potassium sulphate as it forms and prevents it from coating the cyanid not yet in solution. In the presence of an insufficient amount of water, the potassium sulphate is not completely dissolved, but forms a coating on the pieces of cyanid, preventing the sulphuric acid from penetrating to it, and thereby retarding, or even in part preventing, the reaction. In such cases this undissolved potassium sulphate usually congeals, causing the pots to "freeze." The phenomenon always occurs where the formula is 1–1–1, or where the same amounts of water, acid, and cyanid are used. On agitating the congealed residue by stirring, it is almost always possible to find small pieces of undissolved cyanid enveloped in a coating of the potassium sulphate. Ordinarily, when the residue is stirred the particles of cyanid are removed, to some extent, from this envelope of potassium sulphate, allowing some of the unused acid to reach them, and thus evolving a small amount of gas without the addition of more acid. Under these conditions, however, the reaction is never complete, and it is highly desirable therefore to add sufficient water at the beginning to dissolve all the potassium sulphate.

From this last statement, as well as the data presented under the heading "The effect of too great an excess of acid" (p. 34), it is seen that the congealing or "freezing" of generating jars is due to either or both of two conditions: (1) An insufficient amount of water to completely dissolve the sulphate of potassium, or (2) a large excess of sulphuric acid, whereby the water is rendered less capable of taking into solution the same amount of sulphate as it otherwise would.

Another very important function of the water in the reaction is the heat produced by the union of the sulphuric acid and water. Potassium cyanid introduced into this heated mixture gives off hydrocyanic-acid gas much more quickly and thoroughly than at a lower temperature, and in field work rapid generation of gas is essential.

THE EFFECT OF DIFFERENT PROPORTIONS OF WATER ON THE TEMPERATURE OF THE GAS.

Anyone who has watched the escaping gas and steam from the reaction of potassium cyanid and sulphuric acid wherein different proportions of water were used could not fail to notice that the violence with which the generation starts and the gas is given off is apparently greatest with the smaller proportions of water. Fumigators are aware of this, and commonly increase the proportion of water when using large amounts of cyanid. Practice has demonstrated that with a greater proportion of water the injurious effect of the resulting gas on the leaves and fruit is materially lessened. The lessening of the injury has been attributed to the fact that the escaping gas was less heated when large proportions of water were used. In order to clear up this point an experiment was performed, the results of which are given in Table II.

Table II.—*Experiment to determine the effect of different proportions of water on the temperature of the resulting gas.*

Amount of chemicals used.			Temperature of the acid and water mixture.	Highest temperature of the hydrocyanic-acid gas.	Temperature of the gas one minute from start of generation.
Cyanid.	Acid.	Water.			
Ounces.	*Ounces.*	*Ounces.*	°*F.*	°*F.*	°*F.*
5	5	5	180	124	115
5	5	10	190	126	121
5	5	15	170	128	109
5	5	20	160	128	105
5	5	25	145	118	105
5	5	30	136	108	104
5	5	40	125	90	87

In this experiment 5 ounces (avoirdupois) of cyanid and 5 ounces (fluid) of acid were used for each test. The proportions of water were varied, 5, 10, 15, 20, 25, 30, and 40 ounces, respectively, being used. As a result the proportion of water to 1 part of acid or 1 part of cyanid was 1, 2, 3, 4, 5, 6, and 8, respectively, for the different tests. These generations were made in a 1½-gallon fumigating vessel in a room. The temperature of the escaping gas was taken at the mouth of the pot. The temperature of the acid-water mixture was taken one minute after pouring the two together. The cyanid was then added.

The maximum temperature of the escaping gas is always realized within the first minute, usually thirty to forty seconds after the generation commences. Examination of the maximum temperature of the gas as noted in the third column of the table above indicates that the temperature of the gas is reduced when large proportions of water are used. When using from 1 to 4 parts of water, the temperature is nearly uniform, but with 5 parts of water the decrease becomes marked. Repetitions of the above experiment gave similar results. The violence of the reaction and the temperature of the gas are affected more or less by the size of the pieces of cyanid. A very violent reaction results from the use of cyanid in powdered form.

We would expect that to increase the proportion of water would decrease the temperature of the gas. One reason is shown in this table under the column marked "Temperature of the acid and water mixture." As the proportion of water to sulphuric acid becomes larger the resulting temperature of the mixture is lessened. Hence when the cyanid is added to the mixture as high a degree of heat to start the reaction is not developed as when the smaller proportion of water is used, and in consequence gas is evolved less violently.

THE TEMPERATURE OF THE GAS WHERE LARGE AND SMALL DOSAGES ARE USED.

In an experiment to determine the temperature of the gas resulting from large and small dosages (Table III) the chemicals were used in the following proportions: Cyanid 1 part, acid 1 part, and water

3 parts. The reactions were accomplished in 2-gallon earthenware fumigating vessels in a room where the air was moderately quiet. The temperature of the gas was taken at the mouth of the vessels.

TABLE III.—*Experiment to determine the temperature of the gas resulting from large and small dosages.*

Amount of chemicals used.			Highest temperature of mixture of acid and water.	Time after mixing when temperature of mixture is highest.	Temperature of mixture at end of one minute.	Highest temperature of hydrocyanic-acid gas.	Time after generation when temperature of gas is highest.	Temperature of gas one minute from generation.	Temperature of gas two minutes from generation.
Cyanid.	Acid.	Water.							
Ounces.	*Ounces.*	*Ounces.*	°*F.*	*Seconds.*	°*F.*	°*F.*	*Seconds.*	°*F.*	°*F.*
3	3	9	135	30	131	100	30	83	73
6	6	18	163	35	157	130	30	104	86
8	8	24	167	25	160	135	30	106	92
10	10	30	170	25	164	132	30	103	90
12	12	36	164	30	157	140	30	113	95
14	14	42	178	25	173	145	25	116	98
16	16	48	173	25	161	152	25	118	99
20	20	60	172	25	168	153	25	123	106

An examination of this table shows that the temperature of the escaping gas increases somewhat as the dosages become larger. Hence if heated gas is more injurious than cooler gas, we would expect more burning as a result of the increased dosages. This is exactly what does happen to some extent in field operations. It is interesting to note that the highest temperature of the acid-water mixture occurs about one-half minute after the mixing takes place. The highest temperature of the hydrocyanic-acid gas occurs about one-half minute after the generation commences, and then the temperature of the gas rapidly decreases during two to two and one-half minutes, at the end of which time most of the gas has been evolved. At the expiration of from three to five minutes the generation of gas has practically ceased.

THE EFFECT OF DIFFERENT PROPORTIONS OF WATER ON THE AMOUNT OF AVAILABLE HYDROCYANIC-ACID GAS.

In the course of this investigation an experiment was made to determine the amount of hydrocyanic-acid gas available when generated with different proportions of water. The results as determined by the Bureau of Chemistry of this Department are given in the accompanying chart (fig. 13).

In these experiments commercial sulphuric acid, 66° Baumé or 92.77 per cent pure, and potassium cyanid 97.12 per cent pure were used. Three ounces (fluid) of sulphuric acid and 3 ounces (avoirdupois) of potassium cyanid were employed in each experiment, and 3, 6, 9, 12, 15, 18, 21, and 24 ounces, respectively, of water were used in the different experiments.

From the following chart it is evident that with the acid and cyanid mentioned the largest amount of gas is available from two parts of water. As the proportion of water is increased above two parts the avaliable gas is decreased until with eight parts of water we obtain only about 43 per cent of gas, or less than one-half as much as with two parts. In other words, 1 ounce of cyanid and 1 ounce of acid in combination with 2 ounces of water will produce much more available gas than 2 ounces of cyanid and 2 ounces of acid with 16 ounces of water.

The cause for the smaller amount of gas with one part of water than with two parts has already been explained (see p. 35).

We can see from the chart that the proportion of water used is one of the most important factors in fumigation practice; and many of

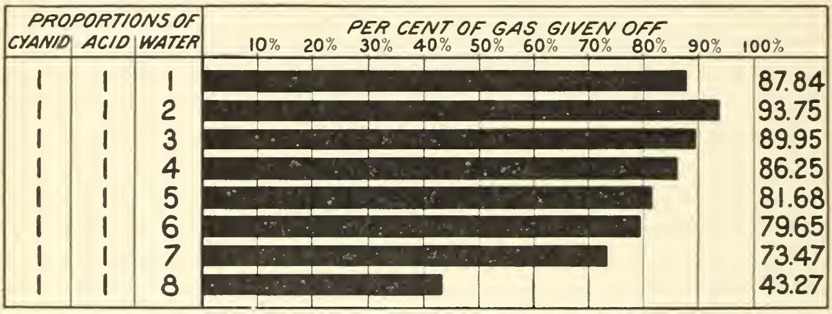

Fig. 13.—Chart showing total amount of gas evolved when different proportions of water are used. (Original.)

the poor results in field work can be directly attributed to the use of too much water. That the water should be measured as carefully as the acid is beyond question.

Aside from variations in the amount of water used, due to lack of precision in measuring, the proportion of water recommended by different authorities on fumigation has varied all the way from two to eight parts. It is no wonder we see widely differing results from the work of different men. It is a common practice with many fumigators to increase the dosage when fumigating a tree that is severely infested with scale. It is also a common practice—in fact, so common as to be almost universal—to increase the proportion of water when using heavy dosages. This is apparently done with a view to preventing injury to the fruit and foliage. In following out this practice the fumigator has many times unconsciously prevented the very result he wished to accomplish—that of obtaining a more concentrated gas.

THE CORRECT PROPORTION OF WATER.

The chart (fig. 13) shows that two parts of water to one part each of cyanid and acid will produce the maximum amount of avail-

able gas. It is impracticable, however, to use two parts of water in field work, for with this proportion of water the residue, especially where small dosages of powdered cyanid are used, will frequently congeal within an hour's time—the usual period for leaving the tents on the trees. Although this proportion of water is apparently sufficient to dissolve the sulphate at first so that a complete reaction takes place, it appears unable to hold the sulphate in solution long enough afterwards to prevent inconvenience in field work. It is of course evident that a "frozen" generator does not always signify an unsatisfactory generation. With three parts of water, however, the residue seldom congeals, and this is the proportion we have used in all of our field work and which we recommend. The water should be measured carefully with a glass or dipper graduated to ounces.

THE MOST ECONOMICAL PROPORTION OF CHEMICALS TO USE IN GENERATING HYDROCYANIC-ACID GAS.

In the preceding discussion it has been shown that for various reasons 1 fluid ounce of commercial sulphuric acid and 1 ounce (avoirdupois) 96 to 100 per cent potassium cyanid in combination with 3 fluid ounces of water give a complete reaction. Thus the 1–1–3 formula, hitherto recommended by the Bureau of Entomology, is fully indorsed.

A review of the use of hydrocyanic-acid gas for fumigation, both in California and elsewhere, shows frequent divergence from the more economical and satisfactory proportion of chemicals indicated above. One book recognized as an authority on fumigation methods recommends the use of "one-half more acid than cyanid and one-half more water than acid." Many of the entomologists and horticulturists in the eastern United States advise in their recommendations for nursery fumigation two parts of acid and four parts of water to each part of cyanid.

MIXING THE CHEMICALS.

It is preferable to pour the water into the generator first and then add the acid. The pouring of the water onto the acid is more likely to cause splashing of the acid from the jar onto the fumigator. When the acid and water are in readiness for generating the gas the fumigator adds the pieces of cyanid to the mixture and hastily retreats. As already stated, the cyanid should be added while the mixture of water and acid is hot. The advantage of this is shown in the following experiments performed by the Bureau of Chemistry of this Department. One ounce of potassium cyanid, 1 fluid ounce of commercial sulphuric acid, and 3 fluid ounces of water were used in each case.

Experiment No. 1.—The potassium cyanid was added to a mixture of acid and water in which the heat was exhausted, and it was found

that 23.25 per cent of hydrocyanic acid remained in solution and was not liberated.

Experiment No. 2.—The potassium cyanid was added to a mixture of acid and water when first combined, i. e., when the heat was great, and it was found that only 10.68 per cent of hydrocyanic acid remained in solution.

CAUTION.—The cyanid should never be placed in the water before the acid is added. If the acid is added to the cyanid in solution, a very violent reaction takes place, which will sometimes throw much of the liquid from the vessel. In one instance about 1 pound of cyanid was dissolved in water in a 2-gallon generator. Acid was then added, producing a disturbance so violent as to throw some of the liquid almost to the top of a two-story barn.

A 1½-gallon generator will serve for a dose of about 15 ounces of cyanid without boiling over, or a 2-gallon generator for approximately 20 ounces.

The residue from the reaction contains more or less sulphuric acid which has not been used. This residue should never be deposited against or at the base of a tree, as it may penetrate to the roots, especially in light sandy soils, destroying a part if not the entire tree.

PURPLE SCALE FUMIGATION.

PRELIMINARY EXPERIMENTS FOR THE CONTROL OF THE PURPLE SCALE.

During the month of November, 1907, experiments were undertaken at Orange, Cal., to determine the dosage required for the destruction of the purple scale (*Lepidosaphes beckii* Newm.) in all its stages, as well as to determine the effect of exposures of different durations. The orchard under treatment contained orange trees varying from 7 to 14 feet in height. The infestation with the purple scale was very severe on many of the trees.

In the first experiment the duration of exposure was thirty minutes. In this experiment a series of tests was made to determine the effect of different dosages. These tests were as follows: One series of trees was dosed at the rate of three-fourths ounce of cyanid per 100 cubic feet of inclosed space; a second series at the rate of 1 ounce, a third at the rate of 1¼ ounces, and so on, increasing the dosage of each succeeding series at the rate of one-fourth ounce per 100 cubic feet. The largest dosage used was 2½ ounces per 100 cubic feet.

The second and third experiments were the exact counterparts of the first in all respects except that the duration of the exposures was respectively one hour and one and one-half hours.

From the data secured from these experiments it should be possible to determine the killing dosage for the purple scale for that particular length of time, provided a sufficient strength of gas was reached. To insure that the dosage sought would fall within the

scope of the schedule, the limits were made very broad. From the difference in strength of killing dosage between these three experiments we would be able to determine the effect of length of exposure on results secured.

To obviate as much as possible the leakage of gas, which would vary in trees of different sizes, trees were chosen of as uniform a size as could be obtained. The cubic contents of the trees chosen for the first two experiments did not vary greatly and the trees ranged between 11 and 14 feet in height. As in the first two experiments most of the larger trees had been used, for the third experiment we were compelled to utilize those remaining, which varied somewhat in size, and were also, for the most part, noticeably smaller than those represented in the first two experiments.

During the latter part of January an examination was made of the results of these experiments. Fully two weeks were devoted to this, and thousands of the purple scale were scrutinized. The method employed was a very careful one. In each case the scales were overturned and examined with a powerful hand lens. In those instances in which the entire contents of the scale were not at once revealed, the delicate ventral scale was ruptured and the contents scraped out. Through this method not a single egg could escape observation.

Four trees were used in each test and an examination to determine results was made of each. This examination included many infested leaves and branches taken as close to the ground as possible and up to 6 or 7 feet above the ground. Infested fruit was also examined when obtainable. The average condition existing in these four trees was taken to indicate the result of the test.

The chemicals were used in the following proportion: Potassium cyanid, 1 part; sulphuric acid, 1 part; water, 3 parts.

TABLE IV.—*Fumigation for the purple scale, experiment No. 1.*

[Length of exposure, thirty minutes; height of trees, 11 to 14 feet.]

Number of trees treated.	Cyanid per 100 cubic feet of space.	On leaves and branches.		On fruit.	
		Insects alive, approximately.	Eggs normal, approximately.	Insects alive, approximately.	Eggs normal, approximately.
	Ounces.	*Per cent.*	*Per cent.*	*Per cent.*	
4	¾	5-6	Over 75.	10	Fully 90 per cent.
4	1	0	About 75.	2	Many normal eggs found under every scale containing eggs.
4	1¼	0	15-20	0	Some normal eggs found under almost every scale containing eggs.
4	1½	0	2-3	0	15 per cent.
4	1¾	0	Less than 1.	0	5-7 per cent.
4	2	0	0	0	1 per cent.
4	2¼	0	0	0	Two instances of apparently normal eggs.
4	2½	0	0	0	None.

In this experiment, when three-fourths of an ounce of cyanid per 100 cubic feet of space was used, live adult females were found on the leaves and branches, but the insects were killed by all greater dosages; normal eggs were found after the use of a dosage as high as $1\frac{3}{4}$ ounces per 100 cubic feet. Live insects were found on the fruit after both the three-fourths-ounce and 1-ounce tests, but were destroyed by the heavier dosages; normal eggs were found on the fruit after dosages up to and including the $2\frac{1}{4}$-ounce rate; with $2\frac{1}{2}$ ounces per 100 cubic feet, all were apparently destroyed.

This experiment indicates that for normally shaped orange trees, from 11 to 14 feet in height, situated in a region with conditions comparable to those at Orange, and exposed to the gas for thirty minutes, a dosage of about 2 ounces per 100 cubic feet is required for eradication of the purple scale from the leaves and branches. If the trees contain fruit infested with scale, it is necessary to increase the dosage rate to $2\frac{1}{2}$ ounces to accomplish the same result.

TABLE V.—*Fumigation for the purple scale, experiment No. 2.*

[Length of exposure, one hour; height of trees, 11 to 14 feet.]

Number of trees treated.	Cyanid per 100 cubic feet of space.	On leaves and branches.		On fruit.	
		Insects alive, approximately.	Eggs normal, approximately.	Insects alive, approximately.	Eggs normal.
	Ounces.				
4	$\frac{3}{4}$	0	1–5 per cent.	0	Many instances.
4	1	0	1 per cent or less.	0	Several instances.
4	$1\frac{1}{4}$	0	2 doubtful cases.	(a)	(a)
4	$1\frac{1}{2}$	0	0	0	One doubtful case.
4	$1\frac{3}{4}$	0	0	0	Few instances of normal eggs on one fruit.
4	2	0	0	0	No instances of normal eggs.
4	$2\frac{1}{4}$	0	0	(a)	(a)
4	$2\frac{1}{2}$	0	0	(a)	(a)

[a] No infested fruit on these trees.

With an exposure of one hour all insects were destroyed on the leaves and branches at a three-fourths ounce dosage rate. All eggs were destroyed at the $1\frac{1}{2}$-ounce dosage rate. Since very few oranges infested with scale were found on the trees used in this experiment, it is considered that further investigation will be necessary before the effect of different dosages on scale infesting the fruit is definitely known. No live insects were found infesting the small amount of fruit available. Normal eggs were found after a dosage as high as the $1\frac{3}{4}$-ounce rate.

This experiment would lead to the conclusion that for normally shaped orange trees, from 11 to 14 feet in height, exposed to the gas for one hour, and situated in a region with conditions comparable to those at Orange, a dosage rate of $1\frac{1}{2}$ ounces per 100 cubic feet will

destroy the purple scale in all its stages on the leaves and wood. If the tree contain fruit infested with this scale it will be necessary to slightly increase the dosage. The exact amount of this increase can not be stated with accuracy at this time, owing to the fact that in the single experiment performed very little infested fruit from which data might be secured was available.

TABLE VI.—*Fumigation for the purple scale, experiment No. 3.*

[Length of exposure, one and one-half hours; size of trees mostly 7 to 10 feet; occasionally one 11 or 12 feet.]

Number of trees treated.	Cyanid per 100 cubic feet of space.	On leaves and branches.		On fruit.	
		Insects alive, approximately.	Eggs normal, approximately.	Insects alive, approximately.	Eggs normal.
	Ounces.				
4	$\frac{3}{4}$	3-5 per cent.	40-50 per cent.	10-15 per cent.	Above 75 per cent.
4	1	1 live female.	20-25 per cent.	1-2 per cent.	65-75 per cent.
4	$1\frac{1}{4}$	0	4-5 per cent.	(a)	(a)
4	$1\frac{1}{2}$	0	1-2 per cent.	0	Two oranges examined; many normal eggs present.
4	$1\frac{3}{4}$	0	3 instances of normal eggs.	0	A few normal eggs.
4	2	0	0	(a)	(a)
4	$2\frac{1}{4}$	0	0	(a)	(a)
4	$2\frac{1}{2}$	0	0	(a)	(a)

a No material for examination.

In this experiment live insects were found on the branches and leaves in the cases where three-fourths ounce and 1-ounce dosages were employed. Normal eggs were found up to and including the $1\frac{3}{4}$-ounce rate, but were destroyed by dosages exceeding this. As in the case of experiment No. 2, so little scaly fruit was available at that time that we are inclined to consider the results in this part of the test as yet incomplete.

THE LEAKAGE OF GAS IN FUMIGATING SMALL TREES.

When the results of experiment No. 3 are compared with those of experiment No. 2 we are at first led to believe that an error has been made. In experiment No. 2 it was found that the $1\frac{1}{2}$-ounce dosage rate destroyed all insects and eggs on the leaves and branches, whereas in this experiment it required one-half ounce more cyanid per 100 cubic feet, or a 2-ounce dosage rate, to accomplish the same result. Since the period of exposure was thirty minutes longer than that of experiment No. 2, we would naturally expect that the results accomplished would be as good or better, all other conditions being the same. The apparatus and chemicals employed were identical in both cases; and the conditions under which the fumigation was conducted were practically the same. There was, however, one difference: The trees involved in the one and one-half hour fumigation were much smaller than those of the one-hour test. This fact accounts for the

less satisfactory results in eradicating the scale, in this experiment. We know that a leakage of gas takes place through the tent and that more gas will escape through 2 square feet of cloth than through 1 square foot in a given time. It will be shown in one of the following discussions that the leakage surface of tented trees is proportionately much greater for smaller trees than for larger ones. This would lead us to expect a greater escape of gas and consequently the requirement of a heavier dosage rate with the smaller than with the larger trees. The last experiment demonstrated the correctness of this deduction.

THE LENGTH OF EXPOSURE.

All considerations were the same in experiments Nos. 1 and 2 except the length of exposure. In using a 2-ounce dosage rate, we were able to destroy the purple scale in all of its stages on the leaves and branches with a thirty-minute exposure, whereas with a one-hour exposure we were able to accomplish the same results by using a 1½-ounce dosage rate. This demonstrates that decidedly better results can be secured by leaving the tents on the trees one hour than is possible with thirty minutes gassing. Whether more favorable results can be accomplished in one and a half hours than in one hour can not be determined from these experiments, since the trees in experiment No. 3 were of a smaller size than those in experiments Nos. 1 and 2. This matter of the large or small size of the trees is a vital factor in affecting the results obtainable.

Judging solely from the data at hand, we are forced to the conclusion that one hour is the more satisfactory length of exposure. Further experiments may show that a longer exposure will produce better results, or even that a forty-five or fifty-minute exposure will produce results as satisfactory as are obtainable in one hour. We hope in the near future to be able to fully settle this question. Until this is done, however, it would appear advisable to adhere to the one-hour length of exposure which is now generally employed in southern California. The considerations upon which this conclusion is based are as follows:

Experiments have demonstrated conclusively that with an exposure of one hour we can obtain decidedly better results than with an exposure of thirty minutes. If we give the tree an exposure of thirty minutes, it will require a considerably larger amount of cyanid to accomplish the same result. It requires approximately one hour for an outfit to go through the complete operation of preparing the chemicals and shifting 30 to 33 tents—the number usually employed. The tent pullers, by the time the end of the row is reached, are usually as much as five minutes, sometimes more, ahead of the one who handles the chemicals. As a result, the last trees of a row are exposed to the gas about fifty-five minutes, or a little less, under the

present system, whereas an hour is supposed to be the length of exposure throughout. Thus if fifty minutes is found to give as satisfactory results as an hour, it would be poor policy to reduce the general exposure to this basis, inasmuch as with a general exposure of one hour some trees are already receiving but little more than fifty minutes.

As a rule, very little gas remains under the tent at the expiration of one hour. The amount is usually so small that the mortality among the scale-insects could be but slightly increased by greatly lengthening the exposure. Various authorities have recommended two hours or more as the duration of exposure, and it is possible that these long exposures would produce slightly better results than an exposure of one hour.

From the standpoint of the fruit grower, who requires the best results at the least possible expense, the item of time is highly important. The question which must be considered is whether it is more advantageous to sacrifice time or cyanid. No doubt it is cheaper to sacrifice time up to a certain point, but beyond this it is cheaper to sacrifice cyanid. As previously stated, the mortality among scale-insects, when a two-hour exposure is employed, might be slightly greater than at one hour. Before advising a two-hour exposure, however, we must determine whether or not it would be more economical to employ an exposure of one hour and use sufficient cyanid to accomplish the same results secured by the longer time. Fumigators are usually paid by the hour. Where tents are left on the trees two hours, with the same number of tents the cost for labor is exactly twice that for one hour. From 4 to 6 men, at an average wage of 35 cents per hour, are used on an outfit (infrequently 3), making the hourly cost for labor from $1.40 to $2.10. This would purchase from 5 to 7 pounds of cyanid.[a] Under these circumstances, if we can obtain as good results in an hour by using 5 to 7 pounds more of cyanid—or a smaller amount, according to the number of men in the outfit—it would be more economical in the end to use the additional cyanid and expose for the shorter time. The writer's own field experience leads him to believe that as good results can be accomplished in one hour as in two hours by using an amount of cyanid costing far less than would the extra hour's labor.

It will be seen that the question before the fumigator is not simply one of using that length of exposure which will produce the best results, but that which will at the same time be most economical. From field experience and other considerations the writer is led to believe that this will be between fifty minutes and one and one-half hours.

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[a] Cyanid is here considered as including acid, both costing about 28 cents per pound.

ERADICATION OF THE PURPLE SCALE.

The foregoing experiments have shown that the purple scale can be eradicated from citrus trees, provided a dosage of sufficient strength be used with a sufficient exposure. This dosage strength is much greater than that at present used in fumigation.

If the purple scale can be everywhere eradicated by using a dosage of definite strength (which we hope to determine in due time), the question will immediately arise in the orchardist's mind whether it will be profitable to use this heavier dosage provided it can be employed without injury to the tree and fruit. In deciding this question several practical considerations must be taken into account. The trees, as will be shown later, are in a condition to stand this heavy dosage without injury during but a limited portion of the year. It would be impossible for the number of outfits at present in existence to fumigate the infested area within this limit of time. Moreover, unless compelled to do so the orchardists in any locality would not all use this dosage. Whether it would be advisable for a grower to incur the additional expense for this heavier dosage in his orchard when the infested orchards on all sides of him are fumigated with lighter dosages, if at all, must be determined by large-scale tests. The foregoing are some of the difficulties in respect to the use of this heavy dosage.

DIFFICULTY OF DESTROYING THE SCALE ON THE FRUIT.

There is one more important point which must be considered in connection with fumigation for the purple scale. It will be seen in an examination of the data from the foregoing experiments that an orchardist, fumigating trees containing purple scale in its different stages on the fruit as well as on the leaves and branches, would, except with the heaviest dosages, leave on the fruit healthy eggs soon to hatch and infest other parts of the trees. It would be impractical under most circumstances to use a dosage heavy enough to destroy the eggs on the fruit. The cost of the extra cyanid required, above that necessary for the destruction of the eggs on the leaves and branches, would be more than the scaly fruit is worth. Therefore in fumigating for eradication it is advisable to remove the infested fruit, and it is advisable to remove the old scaly fruit in any fumigation. At picking, fruit badly infested with scale is usually left on the tree, and frequently from one to a half dozen or more old, scale-infested oranges per tree remain throughout an orchard. Even after a good fumigation one of these old fruits might carry more healthy purple-scale eggs than all the rest of the tree, and on the hatching of these eggs the insects will spread to other parts of the tree. The danger from old scaly fruit is evident and all such should be removed from the trees before fumigating an orchard.

GENERAL CONSIDERATIONS.

LEAKAGE OF GAS DURING OPERATIONS.

One of the most important questions relating to the proper dosage in fumigation is that of the leakage of gas through the tent; in fact, the dosage depends directly upon the leakage. To measure with accuracy the amount of gas which escapes through tenting fabrics of various grades during a given length of time, or the rapidity with which the gas within the tent is diluted under different conditions, is a difficult problem. In this work, as far as we have progressed, no attempt has been made to measure directly with instruments the rapidity with which the gas is diluted, but rather to measure it indirectly and roughly through determining the effect on insects by using different durations of exposure. The easiest and most practical method of determining the influence of leakage is by fumigating trees of the same size, in which all factors affecting the results are identical with the exception of the length of exposure.

There is, however, one consideration of value relative to the leakage of gas, which it is quite necessary to understand in successfully fumigating an orchard containing trees of a wide range of size. In geometrical figures which approximate in shape a citrus tree, the volume decreases at a more rapid rate than does the surface area. In order to bring out the relation of this fact to orchard fumigation, the following table has been prepared:

TABLE VII.—*Leakage of gas from tents covering trees of different dimensions.*

Dimensions of tree.		Contents or volume of tented tree.	Exposed surface of tent.	Leakage surface as per cent of volume.[a]
Around.	Over.			
Feet.	*Feet.*	*Cubic feet.*	*Square feet.*	*Per cent.*
20	12	99	85	86
30	19	364	205	56
40	28	1,040	420	40
50	36	2,147	675	31
60	44	3,819	995	26
70	54	6,605	1,445	22

[a] The comparison here and in the discussion which follows is between square feet of surface and cubic feet of volume.

Taking the first tree, 20 feet around by 12 feet over, representing a volume of 99 cubic feet and an exposed surface area of 85 square feet, the ratio of leakage surface to volume is 86:100. For each cubic foot of volume within that 20 by 12 tree there is 0.86 square foot of leakage surface in the tent. The tree 40 by 28 feet has 0.4 square foot of leakage surface for each cubic foot in the tent, while a tree 70 by 54 has but 0.22 square foot of leakage surface to each cubic foot within. Suppose that these tented trees were charged with gas and that all the gas were to escape through the tent. In the

first tree, 20 by 12 feet, there would be 0.86 of a square foot of tent surface for each cubic foot of gas to escape through; whereas in the last tree, 70 by 54, there would be only 0.22 of a square foot of tent surface for each cubic foot to escape through. This would mean that there would be about four times as great an opportunity for leakage, or that the leakage would be approximately four times as rapid in the smaller tent as in the larger one.

There can be little doubt that the leakage of gas in tents covering different-sized trees is nearly in accordance with these figures. Hence it can be readily seen that, in order to secure uniformity of results, this leakage must be taken into consideration, and small trees must receive more cyanid per 100 cubic feet than do the larger trees.

The correctness of the foregoing deduction has been frequently demonstrated in the field. In using on a smaller tree a certain dosage strength with which on large trees we were able to secure splendid results against the purple scale, we were always much less successful. In other words, if we used 1 ounce of cyanid per 100 cubic feet on the 70 by 54 foot tree, we would get far better results than had we used the same dosage rate on the 20 by 12 foot tree. A very forcible exemplification of this condition has been given in experiment No. 3, in fumigating for the purple scale. In this particular experiment much less satisfactory results were secured on the small trees when using a one and one-half hour exposure than on the large trees of experiment No. 2, with a one-hour exposure.

TIME OF THE YEAR FOR FUMIGATION.

Although fumigation is carried on in California at all times of the year, there are certain periods in which the operations are more general. There are two main factors to be taken into consideration in fumigating, i. e., the species of scale-insect and the condition of the tree. As to the latter, it may be said that at certain periods of the year trees are in such a tender condition that they can not withstand a heavy dosage without injury, especially to the fruit.

The bulk of fumigation in California at the present time is carried on between the latter part of August and December. Probably the principal reason for fumigating during this period is that at this time the black scale is most successfully reached. The eggs of the black scale, and the insects themselves when full grown or nearly so (commonly spoken of as in the "rubber" stage), require very heavy dosages. On the other hand, the young of the black scale, or those which have not reached the so-called "rubber" stage, can be destroyed with a moderate dosage. Although the life history of the black scale has never been thoroughly worked out for the region with which we have to do, it is generally understood that the majority

of the insects of the large and more regular brood are hatched and in their least resistant stage during September and October. In some favorable seasons the eggs are almost all hatched in August. Moderately light fumigation dosage may be used against the black scale during this period with success.

The black scale occurs in practically every citrus-growing locality of southern California, while the purple, red, and yellow scales, the other principal citrus pests, are more localized. A heavier dosage is used for the latter insects than for the black scale. Where the other species occur in orchards infested with the black scale, it is a common practice to fumigate during the regular black-scale period, using the heavier dosage. The majority of these scale insects can thus be caught at one time. When fumigating for the purple scale alone, operations may be commenced as early in the season as the trees are in a condition to withstand the heavy dosage without injury, although probably it would be preferable to fumigate a little later in the fall. The purple scale is to be found in the egg stage throughout the year. There is a period in the fall and one in the early spring, however, during which the smallest proportion of eggs is to be found. With dosages lower than those of eradication, the best work can be accomplished at these times.

The red and yellow scales are viviparous and can be successfully destroyed throughout the year.

In fumigating for any of the scale-insects there is one point worthy of consideration. Aside from trying to save the tree from destruction or from having its vitality impaired by the attack of scale pests, the orchardist fumigates principally in order to have his fruit come into the packing house as clean as possible. It would be well, therefore, to fumigate as nearly as possible to the time which would insure him the cleanest fruit. Although lemons are gathered throughout the entire year, the bulk of the orange crop is taken during the first six months. Thus fumigation during the fall and early winter would be sure to place the cleanest fruit in the packing house. If carried on in the late spring or early summer, such insects as remain undestroyed would have the opportunity to breed through a period of several months and infest much fruit.

FUMIGATION DURING THE BLOSSOMING PERIOD.

The statements by experts on fumigation as to the amount of injury resulting from work while the trees are in blossom are very conflicting. Some fumigators hold that a very light dosage will destroy the tender blossoms, while others believe that the blossoms will stand a heavy dosage. In order to decide this point much experimentation was carried on and many observations made throughout

the blossoming period of 1908. Some of the results secured are given in the following paragraphs.

Experiment No. 1.—On February 28 and 29 about one-third of an acre of mixed Valencia and Navel orange trees was fumigated at Upland, Cal., using dosage rates of 1 ounce and 1½ ounces per 100 cubic feet. The trees were about 12 feet in height. At this time the blossoms were just appearing on the trees, none of them being far enough advanced to open. The general conditions of the blossoming may be understood by an examination of figure 14. This

FIG. 14.—Orange blossoms at an early stage of development. (Original.)

may be considered the tenderest stage of blossoming. An examination of these trees two weeks later showed that no apparent injury had resulted and that the trees at this time contained as heavy a set of blossoms as the surrounding unfumigated trees.

Experiment No. 2.—On March 30 fully 1 acre of Navel and Valencia orange trees about 10 feet high were fumigated at Orange, Cal., using dosage rates of 1, 1½, and 2 ounces per 100 cubic feet. The condition of blossoming at the time of fumigation ranged from no open blossoms on some trees to full blossoms on others. An examination of these trees at a later date showed that with the 1 and 1½ dosage rates no apparent injury had been done. The 2-ounce rate had caused

a considerable percentage of the blossoms to drop, yet not enough to lessen the coming crop of fruit to any great extent, if at all.

Experiment No. 3.—During the months of April and May, 25 acres of Valencia and Navel oranges at Glendale, Cal., were fumigated by an expert under the direction of the Los Angeles horticultural commission. While this fumigation was in progress, trees could be found in all stages of blossoming, from those with blossoms just appearing to those in full bloom. The dosage rate used was estimated to be from three-fourths to 1 ounce per 100 cubic feet. Of course this rate varied with different trees, since the dosage was estimated after the usual guesswork method. Several examinations of the orchard were made. Although blossoms were injured on some of the trees, the number was so small as in no way to lessen the future crop of fruit.

Other instances might be mentioned, but the results correspond practically with those in the three experiments already described. Trees in which there were blossom-shoots and tender leaf-shoots side by side would have the leaf-shoots burned back while the blossoms remained uninjured. Also numbers of cases could be found where the tender leaves on the blossom-shoots were burned while the blossoms themselves remained uninjured. This, as well as the heavy dosage which the blossoms will stand without injury, would lead us to conclude that the blossoms will stand a heavier dosage than the tender leaves and leaf-shoots. These experiments also show that fumigation can be safely conducted during the blossoming season, using such dosages as are at present generally employed by fumigators, or are advised in dosage schedule 1 (p. 65).

FUMIGATION WHILE THE FRUIT IS OF SMALL SIZE.

Experiments and observations to determine the effect of fumigation on fruits of various sizes, and more especially on small fruits, were made during the season of 1908. Conflicting opinions on this subject are prevalent.

Experiment No. 1.—On June 16 two Valencia orange trees about 8 feet in height, in a healthy condition, and containing young fruit from three-eighths to one-half inch in diameter, were fumigated at the 2-ounce dosage rate. Fully 25 per cent of the fruits on these trees were pitted or burned.

Experiment No. 2.—On June 24 a somewhat unhealthy Navel orange tree about 12 feet in height, with the fruits about one-half inch in diameter, was dosed at the rate of 1½ ounces. Fully 50 per cent of the fruits were pitted. Two healthy Valencia orange trees about 10 feet in height, with fruits practically the same size as in the case of the Navel tree, received a dosage at the rate of 2 ounces. About 40 per cent of the fruits were burned.

Experiment No. 3.—On July 11 and 13, four Valencia orange trees were fumigated, using a $1\frac{1}{4}$-ounce dosage rate, 4 trees receiving a $1\frac{1}{2}$-ounce dosage, 8 trees a $1\frac{3}{4}$-ounce dosage, and 4 trees a 2-ounce dosage. These trees were in a perfectly normal condition, about 7 to 8 feet high, and contained young fruits fully three-fourths of an inch in diameter. With the $1\frac{1}{4}$-ounce dosage rate no fruit was burned; with the $1\frac{1}{2}$-ounce rate an occasional orange was slightly burned; with the $1\frac{3}{4}$-ounce rate a very small percentage was burned, while with the 2-ounce rate a considerable percentage was injured. This demonstrates that a 2-ounce dosage rate could not be safely used on trees of this size.

Experiment No. 4.—During the middle of July a large number of orange trees of all sizes were fumigated at Santa Fe Springs, Cal., using various dosage rates. The trees fumigated were of several varieties, in a healthy condition, and all well filled with fruits about the size of an English walnut and slightly larger. It was found from this experiment that a dosage rate of 1 ounce to 100 cubic feet could at this time be used without injury on orange trees 15 to 16 feet high. Only an occasional orange was burned by $1\frac{1}{4}$ ounces. Smaller trees proved able to stand a heavier dosage than larger ones without appreciable injury.

On the basis of information obtained from experiment No. 4, dosage schedule 1 (p. 65) was prepared. This schedule was put into use during the latter part of July and has been in use, up to the time of writing, by two outfits, at Whittier, Cal. Although no noticeable injury to the fruit has resulted from the use of this dosage, the general effect on the tree has indicated that a heavier dosage could not have been used with safety.

A further example of the tender nature of small fruits was shown in some work done by an excellent fumigator at Downey, Cal., during the latter part of May. The fruits were for the most part three-eighths of an inch or less in size, while the trees were thoroughly infested with scale and in a generally unhealthy condition. So far as could be determined, a dosage rate of approximately three-fourths to 1 ounce was used. The larger percentage of the fruits on these trees was burned. Other instances of like fumigation, where the fruits were one-fourth inch or less in diameter, have been seen. The fruit at this period is very tender. Doubtless it is the most critical period of any during which fumigation is conducted.

From the foregoing, it is evident that heavy dosage can not be used while the fruits are small without more or less injury, and that the most critical period during which fumigation may be conducted is between the time when the fruits are set and the time when they attain the size of a walnut.

SIMPLE METHOD OF REMOVING ACID FROM DRUMS AND CARBOYS.

The writer has at times been obliged to employ rather awkward methods in drawing acid from drums and carboys, and other fumigators have doubtless met with the same trouble under like circumstances. Brief mention will be made of some of the best methods which have been brought to notice to obviate this difficulty.

From drums.—The best method of taking acid from drums known to the writer is that at present in use in San Bernardino County and is shown in figure 15. The apparatus consists of a lead-lined tank large enough to hold a drum of acid and having an outlet through

FIG. 15.—Lead-lined tank used in San Bernardino County for removing sulphuric acid from drums and for filling jugs. (Original.)

which the acid may be drawn into carboys, jugs, or whatever vessels are preferred for field use. A drum of acid is rolled from the wagon upon two parallel beams and along these beams onto a small turntable at the tank. This turntable is then revolved through a quarter circle, permitting the drum to be rolled out over the lead-lined tank, into which the acid is then allowed to flow. The acid may be drawn as previously mentioned. The outlet is made of lead tubing, fitted at the tank end with a lead valve by which the flow is regulated.

Another very satisfactory way of drawing acid from drums came to the writer's attention in examining some operations at Glendale, Cal. It consists in the use of a short iron pipe threaded at one end

so as to fit the opening in the drum. The one difficulty with this device is that the flow of acid is uneven and spouting. To offset this, Mr. William Wood, of Whittier, Cal., has contrived a small copper tube for attachment to the pipe, one end of the tube being exposed to the open air, the other end extending up above the level of the acid within the drum, thus allowing an uninterrupted flow of air into the latter. This apparatus is illustrated in figure 16.

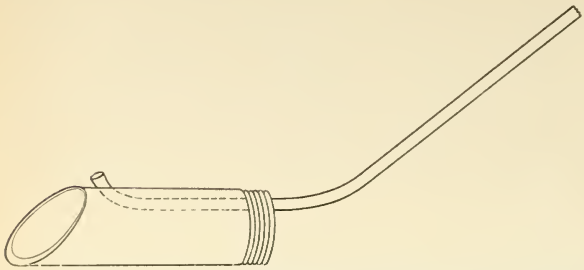

Fig. 16.—An improved pipe for removing acid from drums. (Original.)

A third method in use is to transfer the drums from the wagon to a platform 2 or 3 feet high. The acid may then be removed very easily by means of a piece of rubber hose employed as a siphon (fig. 17).

Fig. 17.—Siphoning acid from drums by means of a rubber hose. (Original.)

From carboys.—Two common methods used for removing acid from carboys in the field are shown in figures 18 and 19. In the first method a small amount of dirt is placed against one side of the car-

boy, furnishing a sort of rest when the latter is tipped to remove the acid. It is well to scoop out a small pit below this ridge of dirt, into which the vessel receiving the acid may be lowered when the acid is so largely removed that it is necessary to turn the carboy far on its side in order that all may be withdrawn.

In figure 19 the handles on the carboy are substitutes for the heap of dirt and the pit. They are also of service in carrying the carboy.

THE PROTECTION OF CYANID.

Many fumigators do not attempt to cover their cases of cyanid, but leave them open during the day. This not only constitutes a source of danger to various animals, but also during the wet season allows water to reach the cyanid. Figure 20 shows a simple lid covered with zinc which is suitable for placing on a cyanid case to protect its contents.


FIG. 18.—Carboy resting against a heap of dirt to facilitate pouring the acid. (Original.)

HYDROCYANIC-ACID GAS IN DRUMS.

Some discussion has arisen during the past year relative to the possibility of introducing hydrocyanic-acid gas into drums under pressure, and using it directly from the drums, thus doing away with all generation in the field. The use of this gas under pressure from drums is impossible at the present time for two reasons: (1) No drums are made which will hold hydrocyanic-acid gas without corroding; (2) we know of no instrument which will measure gas accurately under varying degrees of pressure, such as would exist in removing a gas under pressure from drums.

THE MARKING OF TENTS.

Before new tents are marked they should have been in use for a short time, so that they will be thoroughly shrunken. This shrinking

may be accomplished, in regions of heavy dews or fogs, by simply leaving the tents exposed in the open for a few days. Dipping in water or sprinkling by means of a hose and then allowing the tent to dry in the sunshine will answer the same purpose if repeated several times. The shrinkage of a new 45-foot tent will sometimes be as much as 3 feet. Tents marked before being shrunk will have erroneous graduations.

Fig. 19.—Carboy with handles attached to facilitate pouring the acid and carrying the carboy. (Original.)

The most satisfactory material to use in marking tents is diluted printer's ink. This ink is commonly used in California in marking walnut bags. If the ink is too thick to mark freely, it may be diluted with kerosene. Printer's ink does not cause the cloth to deteriorate. A mixture of lampblack and turpentine may also be used with entire safety. The latter, however, will sometimes rub off to a slight extent.

A DEVICE FOR COVERING FUMIGATION GENERATORS.

During the course of this investigation much effort has been directed toward perfecting a device for attachment to the top of the commonly used open-style fumigation generator that will serve to interrupt the direct rise of the hydrocyanic-acid gas. The result of these efforts, in which the writer was greatly aided by Mr. Frederick Maskew, is shown in figure 21. The device itself consists of a copper cover of such size as to make it available for use with any of the regular-pattern generators now employed by the fumigators of southern California. It is stamped in a concave form from a sheet of copper, with corrugations to permit the escape of gas. The shape is such as to conform to the size of the opening of generators of different capacities and also to direct the course of the escaping gas downward and distribute it uniformly through the lower part of the

tent. It is attached to the generator by hinges of stout copper wire secured by a key bolt passing through the handle. The cover is raised by a slight pressure of the thumb on a projecting piece which is curved in such a manner that the cover will remain in an upright position when so required. When the generator is emptied of its contents, the cover swings clear by its own weight. A glance at the illustration will satisfy the practical fumigator that it is adapted to all the requirements of rapid work in the dark, while its use has demonstrated that it is simple, strong, and durable. It is very possible that if the copper cover were lined with a thin covering of lead its durability would be increased.

FIG. 20.—Zinc-covered top for protecting cyanid in the field. (Original.)

A common result of the use of heavy dosages of fine fragments of cyanid is the burning and ultimate dropping of many of the leaves directly above the generator in the pathway of the rapidly rising gas. This result is usually spoken of as the "chimney" effect. The generator cover eliminates this "chimney" burning.

A second and highly important point is the effect of open generators on the tent. The outer part, or skirt, as it is sometimes called, of fumigating tents is constantly being perforated with small holes, even when used by the most careful of workers. We have noticed this effect to some extent in our own outfit, which we believe to be as carefully handled as any fumigation outfit could be. These holes are known to be acid burns. A few simple tests have demonstrated conclusively that many of these acid holes are due to acid carried along with the escaping gas and reaching that part of the tent nearest the generator. By placing large pieces of canvas in the path of gas escaping from open generators in which dosages similar to those often used in field work are employed, it was found that drops of acid reached the canvas as high as 5 feet from the ground. The writer has frequently seen generating vessels placed not more than 2 feet inside the tent. At such a distance one can readily see that

drops of acid might reach the tent. The generator cover described above so deflects the gas, and incidentally such acid as is carried with it, that the drops are thrown to the ground, thus saving the tents. The decreased cost in mending of tents will doubtless pay for the cost of such a cover device several times over in a fumigating season.

A third advantage, which we have not as yet demonstrated but which we have reason to believe will develop, is a better distribution of gas through the tent. Heretofore the most difficult part of the tree in which to destroy insects is the lower part. This is also the part of the tree in which the purple scale is largely to be found. With the open generator the gas rises straight up in a narrow column for several feet (fig. 22, at left), being broken up and distributed through the top of the tree first. As the gas is lighter than air, it is not to be expected that it will quickly become uniformly distributed throughout the bottom of the tent, even if at any time it becomes as concentrated here as at the top. The greater burning effect and better killing effect in the top of the tree would tend to substantiate this assumption. Field observations in fumigating large trees show that the gas is of no great strength at the lower part of the tent for several minutes after the charge is set off. With this new cover the gas is broken up and distributed through the bottom of the tent first (fig. 22, at right). By the time it reaches the top it is pretty generally distributed throughout the tent. As the bottom of the tree is the first to receive the full benefit of the gas, a more complete killing of scale at the bottom of the tent may be expected than with an open generator.

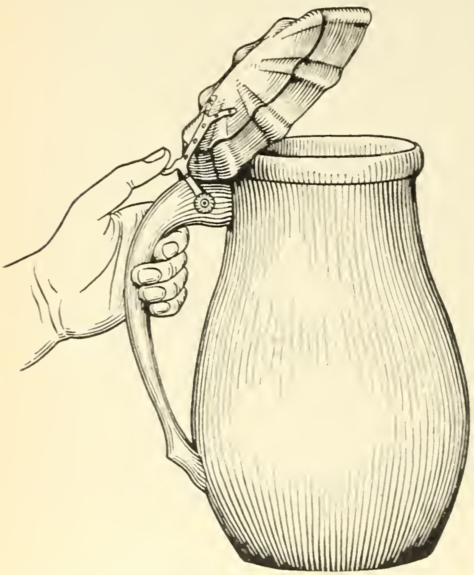

Fig. 21.—A cover device attached to a fumigation generator; corrugations in cover allow gas to escape. (Original.)

AN IMPROVED SYSTEM OF FUMIGATION.

During the month of July, 1908, a system of fumigation which has decided advantages over the old method was introduced into California field practice. In this system the tents are marked after the Morrill method, described on pages 27–30 (figs. 11 and 12). Only the three parallel lines are used, the cross line being unnecessary

and to some extent a disadvantage in practical work. The marking on these lines gives us an easy means of determining the distance over the top of the tree. Our experience has shown that the distance around the tented tree can be measured very accurately by pacing. The one whose work, in a regular outfit, is to obtain the dimensions of the trees, should make several practice trials in advance of fumigation, so as to determine the exact length of his pace, and to regulate it, if necessary. In pacing the distance around a tree it is well to keep far enough from the edge of the tent—say from 6 inches to 1 foot distant—to prevent the body from coming into contact with it. The length of the pace should be regulated to 2½ or 3 feet when approximating the actual distance around the tented tree, preferably 3 feet, if the pacer can step that distance without much exertion. In reality the distance paced will be slightly greater than the actual circumference of the tent. From these two measurements (the distance around and the distance over), it is possible to approximate the cubic contents of the tree.

FIG. 22.—Difference in the direction taken by gas escaping from an open generator and from one covered with the corrugated lid. (Original.)

SUPPLY CART.

With this system some change is necessary in the character of the vehicle for carrying materials, inasmuch as the measuring of chemicals is conducted at the tree. A two-wheeled handcart of the same general description as that in use by the San Bernardino County outfits has been adopted. The handle of the cart and the arrangement of the lights have been improved upon; while the use of faucets in drawing off the acid and water is also an improvement. One of

the carts equipped for use is shown in figure 23. As purchased the cart bed consists of a plain box fitted with a two-shaft handle. This handle is removed, and is replaced by a tongue having an enlarged link-shaped iron about a foot long, firmly attached at the end. This link-shaped handle is very convenient in field work. The scales for weighing the chemicals are placed on a platform above the center of the box. The cyanid is contained in a tin-lined box in the rear half of the cart, while the acid and water are placed in the front end. A 10-gallon keg firmly attached in a horizontal position to the bed of the cart is a very convenient receptacle for the water. A galva-

FIG. 23.—Cart used with the improved system of fumigation. (Original.)

nized-iron basin like that shown above the keg in figure 23, having an opening at the bottom fitting into the bung of the keg, makes a very satisfactory funnel for filling the keg. The acid may be held in an earthenware jar or a lead-lined tank, with cover firmly attached to prevent slopping.

By way of a cover for the earthenware jar we have used a lead-lined lid, which fits tightly within the top (fig. 24). At the center of this lid is an opening about 6 inches in diameter, around the circumference of which is attached a leaden tube which extends downward several inches and prevents the slopping of acid through the hole. A lead-lined cover fits into the top of this tube. This opening in the cover is for use in filling the jar.

Very few metals will withstand sulphuric acid without corroding. For this reason all the common types of faucets are practically worthless for drawing acid. There is no faucet on the market that is altogether satisfactory for this purpose, although at the present time a manufacturing firm on the Pacific coast is experimenting in the hope of perfecting the necessary article. We have met this difficulty in an entirely practical manner by attaching a three-quarter inch iron pipe to the lower side of the jar and regulating the flow of acid by means of a large pinchcock placed on a short piece of rubber tubing at the end of the pipe (fig. 24, 1, 4, and 5). The flow of acid is rapid and easy to control. Pure rubber is most satisfactory and a fresh piece should be substituted about every other night.

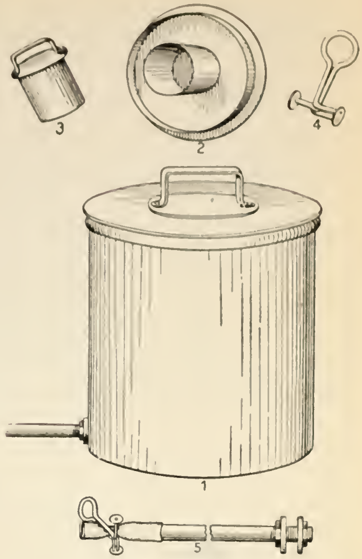

FIG. 24.—Earthenware acid jar with attachments for field use: *1*, Jar complete; *2*, inside view of lead-lined cover showing tube at center; *3*, copper top for opening in cover; *4*, pinchcock; *5*, method of attaching iron pipe to jar, and rubber tube on end of pipe with pinchcock attached.

The water is drawn from a faucet. In order that this may be drawn on the same side of the cart as the acid, a pipe of the character shown in figure 23 is required. The faucet should have an opening of about three-fourths inch to allow a heavy flow and should be of such a type that a half turn will give it a full opening.

As fumigation is usually conducted at night a torch is placed on the front of the cart to furnish a light by which to measure the acid and water; one on the elevated platform is convenient for the man measuring the cyanid.

This style of cart is entirely practicable for almost all fumigation work. The chemicals can be measured quickly and accurately without any slopping of acid or water. The work is also easier on the men in charge than under the old system. On ground which is so rough that a wheeled cart can not be drawn, a portable table may be used. Such a table as is shown in figure 25 can be easily utilized for such a purpose.

PROCEDURE.

Five men are required to operate this system to advantage. Two men pull the tents and kick in the edges around the bottom of the tree. One man takes the measurements of the tree and determines the dosage from a dosage schedule which he carries with him. After determining the dosage he should empty the generator to be used for that tree and have it in readiness by the time the cart arrives. *The*

generator should always be emptied with one and the same hand and with this hand he should never touch the tent; otherwise acid burns

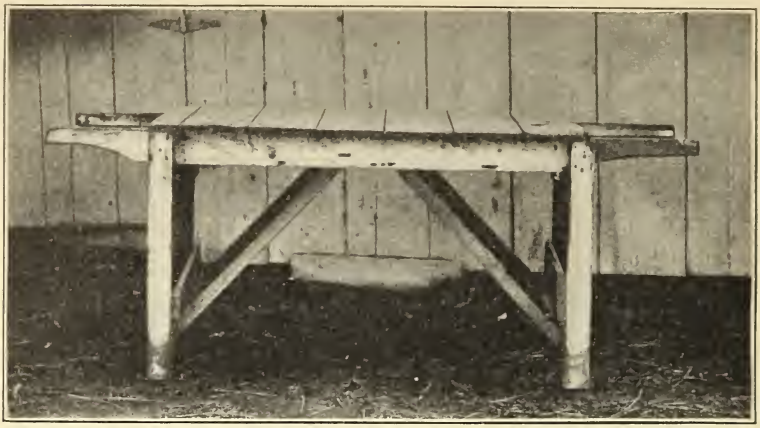

FIG. 25.—A table which can be used instead of a cart in fumigation over very rough ground. (Original.)

may result. The estimator should also be foreman of the outfit, as this is the most responsible position of all. Two men work at the cart. One measures the water and acid, the other weighs the cyanid. The latter holds up the edge of the tent while the acid man places the charge beneath the tree.

FIG. 26.—A row of tented trees, and cart at one end ready for dosing. (Original.)

In actual field practice the cart is first brought up to one end of the row which is to be fumigated (fig. 26). The estimator obtains

his measurements and calls out the dosage. The two men then measure out the required amount of chemicals and dose the tree (fig. 27). While they are thus engaged the estimator has moved on to the next tree, determined the proper dosage, and holds the generator in readiness when the cart is brought up. He then calls out the dosage with which the tree is to be treated. This procedure continues in like manner until the entire row is fumigated.

Outfits employing this system have, on an average, been fumigating a complete set of 32 tents in from forty to forty-five minutes.

FIG. 27.—Dosing a tree. (Original.)

This would appear to demonstrate that the system is entirely practicable from the standpoint of time economy, as tents are usually required to be left on the tree one hour.

ADVANTAGES UNDER THIS SYSTEM.

First.—The element of guesswork in estimating dosage and the consequent waste of cyanid are eliminated, since the dosage is determined according to a uniform method in all cases. If a dosage of sufficient strength to destroy 90 per cent of the purple scale is used, practically 90 per cent of the purple scale is killed on every tree throughout that orchard—not 90 per cent on some trees and 50 per cent, more or less, on others, which has occurred at times under the old method. Or if a dosage strength just sufficient to eradicate the pest is employed, a like result will occur throughout the orchard and there will be no great waste of cyanid by reason of many trees receiving a larger dosage than was necessary.

Second.—An economy of cyanid results from the accurate measurement of the water. Three parts of water are always used, resulting in the maximum amount of available gas for practical work, as already explained (pp. 38–39). Under the old system the water is usually measured with an ungraduated dipper at the tree, and as the cyanid and acid have been previously measured out into small cans, which are in turn placed on a tray to be carried from tree to tree, the schedule is not carried along for consultation in estimating the water, but the required amount of water is guessed at from the amount of chemicals in the cans intended for that particular tree. Owing to the variation in the proportion of water which results in this way, the maximum amount of available gas is seldom produced by the reaction.

Third.—By the old method the cans on a tray sometimes become confused, in consequence of which some trees get the dosage measured out for others. This error is eliminated under the improved system, as the dosage for each tree is measured out just before that particular tree is fumigated.

Fourth.—The tent pullers seldom get more than one or two trees ahead of the cart. As a result, all trees receive the same length of exposure. Under the old system, when the tent pullers got far ahead of the cart at the end of a row, these trees received a much shorter exposure than the first trees.

DOSAGE SCHEDULE.

Having obtained the dimensions of the tented tree, the next step is to determine the dosage. It has been previously stated that the cubic contents can be calculated from these two dimensions. This might be done in the field and the trees then dosed in proportion to the contents. The time required for the calculation of the dosage, however, even after determining the cubic contents of the tree, would not only prevent rapid field work and allow an opportunity for error, but would cause a lack of uniformity in dosage, from the consideration of the cubic contents alone, as will be explained later. This difficulty has been obviated by preparing a dosage schedule from which the required dosage may be learned without any figuring as soon as the measurements of the tree are known.

The orchardists in the citrus section about Whittier, Cal., desired to commence fumigating for the purple scale during the latter part of July. The question immediately arose as to what dosage could be used at that time of the year without injuring the young fruit. As stated under experiment No. 4 (p. 52), while the fruit is small a dosage of 1 ounce to 100 cubic feet could be used on trees from about 10 to 15 feet in height without injury to the fruit, whereas smaller trees would stand a heavier dosage. As this was the limit of dosage which

could be used at that time of the year without injury to the young fruit, the writer prepared a schedule based upon this data.

According to this schedule, trees 41 feet in circumference by 28 feet over the top, from ground to ground, receive 1 ounce of cyanid for each 100 cubic feet of inclosed space. This proportion is increased on smaller trees, while on trees which are larger it is decreased to offset the proportionately smaller leakage (pp. 43–44, 47–48). In preparing the schedule the writer began with a tree 41 feet in circumference by 28 feet over the top. The cubic contents of this tree were determined

	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
10	1	1	1	1½	1½																												10
12	1½	1½	1½	1½	2	2	2½																										12
14	1½	2	2	2½	2½	2½	3	3	3½	4	4½	5																					14
16	2	2½	2½	3	3	3	3½	3½	4	4½	5	5½	6	7																			16
18			3	3	3½	3½	4	4½	4½	5½	5½	6	7	7½	8																		18
			20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
20				3	4	4½	5	5½	5½	6	6½	7	7	8	8½	9	9½																20
22					4½	5	5½	6	6½	7	7½	7½	8	8½	8½	9½	10	10½															22
24						5½	6½	7	7½	8	8½	9½	9½	9½	10	10½	11	11½	12														24
26							7	8	8½	9	9½	10	10½	10½	11	11	11½	12	13	14	14½	15											26
28								8½	9½	10	10½	11	11½	11½	12½	12½	13	13½	14	14½	15½	16											28
								30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
30									10	11	11½	12	12½	13	13½	14	14½	14½	15	15½	16½	17½	18	19	20	20½	21½						30
32											12	12½	13	14	15	15½	16	16½	17	17½	18	18½	19	19½	20½	21½	22½						32
34												13	14	15	16	17	17½	18	18½	19	19½	20	20½	21	21½	22½	23						34
36												14	15	16	17	17½	18	19½	20	20½	21½	21½	22	22½	23	23½	25½						36
38													16	16½	17½	18½	19	20½	21	21½	22	23	23½	24	24½	25	25½						38
													40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
40														17	18	19	20	21	22	22½	23	24	24½	25	25½	26	26½	27	27½	28			40
41														18	19	20	21	22	22½	23½	24	24½	25	25½	26	26½	27	27½	28	28½	29		41
42															20	20½	22	22½	23	24½	25	25½	26	26½	27	27½	28	28½	29	29	30	30½	42
43																21½	22½	23	23½	25	25½	26	26½	27	27½	28	28½	29	29½	30	30½	31	43
44																	23	23½	24	25	26	26½	27	27½	28	28½	29	29½	30	31	31½	32	44
																		50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
45																		24	25	26	26½	27	27½	28	29	29½	30	30½	31	31½	32	33	45
46																		24½	25½	26½	27½	27½	28	28½	29½	30	30½	31	31½	32½	33	34	46
47																		25	26	27	27½	28	28½	29	30	30½	31½	32	32½	33	34	35	47
48																		25½	26½	27½	28	28½	29	29½	30½	31	32	32½	33	34	35	36	48
49																		26½	27	28	28½	29	29½	30	31	31½	32½	33	34	35	36	37	49
																		50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	
50																							30	31	31½	32½	33	33½	35	36	37	38	50
51																							31	31½	32	33	33½	34	36	37	38	39	51
52																							31½	32	33	33½	34	35	37	38	39	41	52
53																							32	32½	33½	34	35	36	38	39	40	41	53
54																							32½	33	34	35	36	37	39	40	41	42	54
																							60	62	64	66	68	70	72	74	76	78	
55																							33	34	35	36	37	37½	40	41	42	43	55
56																							34	35	36	37	37½	38	40½	42	43	44	56
57																							34½	35½	36½	37½	38½	39	41	42½	43½	45	57
58																							35	36	37	38	39	40	42	43	44	46	58
59																							36	36½	38	39	40	40½	42½	43½	45	47	59

FIG. 28.—Dosage schedule No. 1. (Original.)

and a dosage calculated which would give it 1 ounce to each 100 cubic feet. Trees of other dimensions, both larger and smaller, were then considered and their contents determined. In working out the dosage for these trees not only were the cubic contents taken into consideration, but also the rate of leakage as compared with that of the tree 41 by 28 feet. Trees which were smaller than this first tree would have a greater proportionate leakage rate, while the larger ones would have less. In securing the dosage for various trees, those smaller than 41 by 28 feet were given sufficient cyanid in excess of 1 ounce per 100 cubic feet to offset the increased leakage,

while the dosages for larger trees were decreased proportionately below 1 ounce. This allowance for leakage so modified the schedule that trees 24 by 16 feet received as high as 1½ ounces per 100 cubic feet, while trees 60 by 44 feet received only about three-fourths of an ounce to the same space. The results of the use of such a schedule in practical fumigation should be that the smaller and the larger trees receive a dosage of uniform killing power against the scale.

After computing the dosages for trees of such sizes as would include all that could be covered with a tent 60 feet in diameter, a chart was prepared (fig. 28) and the dosages incorporated therein.

How to use the chart.—The top line of numbers, commencing at 16 and continuing through 18, 20, 22, etc., up to 78, represents the distance, in feet, around the bottom of the tent. The outer vertical columns of larger numbers, on either side, commencing at 10 and increasing regularly to 59, represent the distance, in feet, over the top of the tent. The dosage of a tree of known dimensions is found in that square where the vertical column headed by the distance around the tree intersects the horizontal line of figures corresponding to the distance over. For instance, we have a tree 40 feet around by 28 feet over. Looking in the top line of numbers we find 40 next after the third heavy vertical line. The dosages computed for trees 40 feet around are to be found in the vertical column headed by this number, which commences with 6 and ends with 16. Then we glance down the vertical column of large figures at either margin until we come to 28. All dosages computed for trees 28 feet over are found in this horizontal line of figures, which commences with 8½ and ends at 16. The dosage for a tree 40 by 28 feet is found at the intersection of this line with the vertical column headed with 40, that number being 11½, the required dosage of cyanid in ounces. Before the numbers 20, 30, 40, 45, 50, and 55, in the lines at the right and left margins are to be found blank spaces, and in the horizontal lines corresponding to these the numbers at the top of the chart are repeated in that part of the chart containing dosage figures. These numbers, repeated in this manner, make it easier for the eye to locate with certainty the dosage figures sought. In the chart used by the writer, the figures representing distances around and over are printed in red. The lines bounding these columns of figures are also red. All the rest of the lines and figures are black.

This schedule has been called "dosage schedule No. 1," by reason of the fact that 1 ounce to 100 cubic feet of inclosed space was taken as a basis in preparing it, though, as a matter of fact, only a small number of the trees in an orchard receive exactly 1 ounce to 100 cubic feet.

It is not maintained that this table is accurate to the minutest part of an ounce for every dosage, but the writer believes that such

variations as may be found to exist are so small that in practical work in the field the results in killing scale-insects, from the use of any part of the table, will be found as satisfactory as from the use of any other part. Moderately heavy dosages almost invariably burn the tender shoots of a tree to a greater or less extent. Under this schedule practice has demonstrated that the tender growth is uniformly burned back in all cases, whether large trees or small ones are fumigated.

As previously stated in this discussion, dosage schedule No. 1 was prepared for use against the purple scale at Whittier, Cal., during the latter part of July when the fruits in some orchards were about the size of a walnut. The dosage employed was as great as the fruit would permit at that season without injury. This does not indicate that a larger dosage can not be safely used at other seasons of the year, if desired. The writer has at times employed a dosage of double the strength without visible injury to the trees. This was accomplished, however, under more favorable conditions, during the fall and winter months, when the fruit was well grown. It is not deemed advisable to use a dosage against the purple scale of less strength than that of schedule No. 1. If complete eradication is desired, a much heavier dosage must necessarily be employed.

The dosage in schedule No. 1 is equivalent to what is known among many fumigators as the "double dosage." It may be a little stronger than the double dosage of some, rather than weaker. "Double dosage" is usually intended to signify a dosage twice the strength required to destroy the black scale in its earlier stages.

Since this schedule is one of uniformity, it readily permits of manipulation. If a heavier dosage should be desired, such may be obtained by increasing each individual number or dosage in the same ratio; if a lighter dosage, by proportionately decreasing each. The schedule resulting from such increase or decrease will also be one of the same general uniformity as the first. The writer has prepared schedules which are $\frac{1}{2}$, $\frac{3}{4}$, $1\frac{1}{4}$, $1\frac{1}{3}$, and $1\frac{1}{2}$ times the dosage indicated in schedule No. 1.

THE IMPROVED SYSTEM IN USE.

Two outfits of the Whittier (Cal.) Citrus Association commenced the use of this improved system of fumigation, with dosage schedule No. 1, during the latter part of July, 1908. The apparent uniformity of work, indicated by the evenness with which the tender growth was burned back on all trees, immediately attracted the attention of citrus growers who saw the fumigated orchards. Their universal approval of the method is shown by the fact that not a single unfavorable comment was brought to the writer's attention throughout the entire fumigation work. The reception of an improved method

with such unanimous favor by a community of California citrus growers demonstrates its value and economic importance.

Since the first outfits were placed in operation at Whittier, others have adopted the improved system of dosage, and at the time of writing this fully a dozen similar outfits in various parts of Los Angeles and Orange counties, Cal., are using the new method in preference to the old. That such a large number of practical citrus growers in widely separated localities, who have been employing a system of fumigation for many years, should accept an innovation within two months, strongly indicates its superiority.

FUMIGATION SIMPLIFIED.

In the past many persons have been prone to look upon fumigation as a process that is complex and more or less mysterious. In some cases fumigators of years' experience have encouraged this widely prevailing opinion, so that they might themselves be looked upon as experts in a practice difficult to understand and only capable of being successfully performed by men of long experience and special qualifications. This is, of course, erroneous. The improved system outlined in these pages shows how simple the practice of fumigation may be made. Careful men who have never before heard of fumigation can begin the practice of this system and are competent, after instruction for a short time, to secure as good results as might be expected from the most expert fumigator in California. This system reduces fumigation to a matter of simple mechanical operation, entirely intelligible to the average man, and one wherein the operator, to obtain the best results, is required merely to proceed according to the formulas and directions given.

This system makes it possible for the orchardists to possess outfits of their own—either individually or through joint ownership on the part of neighboring fruit growers—and to do the work with their own employees.

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